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**USAAVLABS TECHNICAL REPORT 70-33B**

**EFFECTS OF HIGH-LIFT DEVICES  
ON V/STOL AIRCRAFT PERFORMANCE**

**VOLUME II  
BIBLIOGRAPHY**

By

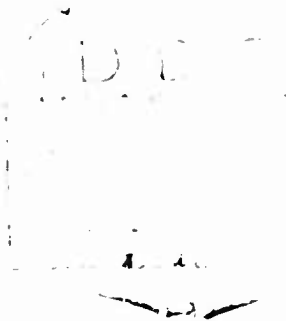
J. Hebert

S. K. Pederson

July 1970

**U. S. ARMY AVIATION MATERIEL LABORATORIES  
FORT EUSTIS, VIRGINIA**

CONTRACT DAAJ02-69-C-0079  
CONVAIR DIVISION OF GENERAL DYNAMICS  
SAN DIEGO, CALIFORNIA



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Task 1F162204A14231  
Contract DAAJ02-69-C-0079  
USAAVLABS Technical Report 70-33B  
July 1970

EFFECTS OF HIGH-LIFT DEVICES  
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VOLUME II  
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by  
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San Diego, California

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FORT EUSTIS, VIRGINIA

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### **ABSTRACT**

This bibliography is a part of the contracted effort "Effects of High-Lift Devices On V/STOL Aircraft Performance," Contract DAAJ02-69-C-0079. All types of high-lift devices are covered. Both experimental and theoretical topics were reviewed, and the selected reports are listed by a subject and an author index.

## FOREWORD

This bibliography presents material obtained from the literature searches conducted as part of the analytical study by the Convair Division of General Dynamics to generate methodology for evaluating the effects of high-lift devices on V/STOL aircraft performance. Selected references from both machine and conventional literature searches are included.

The bibliography covers all types of high-lift devices, including conventional, boundary layer control, and jet flaps, or combinations of these for either deflected slipstream, tilt wing, or tilt propeller configurations. References are not included for lifting fan or lifting jet configurations.

The major sources of information were:

1. Defense Documentation Center Report Bibliography, "High Lift Devices for V/STOL Aircraft," June 1969.
2. National Aeronautics and Space Administration, Linear Tape Searches, for the Convair Division of General Dynamics, June and August 1969.
3. Defense Documentation Center, "Technical Abstract Bulletins."
4. National Aeronautics and Space Administration, "Scientific and Technical Aerospace Reports."
5. Bibliography of NASA Papers on V/STOL Research.
6. AGARD V/STOL Aircraft Bibliography, Second Supplement, 1966.

Abstracts have been included when they could be found. Security classification of the classified documents has been noted where required. Classified abstracts and titles have been purposely deleted to allow this document to be unclassified.

The bibliography contains both a subject and an author index. Since many of the references would fit into multiple subject classifications, each was reviewed and placed only in its major category. The order of subject index listing is primarily by calendar month and year, and the author index is alphabetical.

The effort reported herein was authorized under DA Task 1F162204A14231.

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## II. SUBJECT INDEX

### 1. V/STOL AIRCRAFT STUDIES

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Pocock, P.J. , and Bowker, A.J. , VTOL TRANSPORT AIRCRAFT: A BRIEF DISCUSSION OF CANADIAN REQUIREMENTS AND PROJECT STUDY RESULTS FOR TILTING-WING CONFIGURATIONS WITH TWO PROPELLERS AND FOUR PROPELLERS, NAE LR-204, National Aeronautical Establishment, National Research Council, Ottawa, Ontario, Canada, 1957.

Hiscocks, R.D. , TECHNICAL DEVELOPMENT OF THE DHC-4 CARIBOU UTILITY STOL AIRCRAFT, Paper 59-140, Institute of the Aeronautical Sciences, New York, 1959.

Hartunian, R.A. , Sowyd, A. , and Vidal, R.J. , THE AERODYNAMIC APPRAISAL OF STOL/VTOL CONFIGURATIONS, Paper 60-37, Institute of the Aeronautical Sciences, 1960.

Kelly, M.W. , LARGE-SCALE WIND-TUNNEL STUDIES OF SEVERAL VTOL TYPES, NASA Conference on V/STOL Aircraft, National Aeronautics and Space Administration, Washington, D.C. , 1960.

Kirby, R.H. , AERODYNAMIC CHARACTERISTICS OF PROPELLER-DRIVEN VTOL AIRCRAFT, NASA TN D-730, National Aeronautics and Space Administration, Washington, D.C. , 1961.

Ricard, Czinczenhelm, Jaillard, and de Richemont, THE BREGUET FAMILY OF STOL AIRCRAFT, Preprint 428A, Society of Automotive Engineers, 1961.

Anon., V/STOL MEDIUM RANGE TRANSPORT AIRCRAFT DESIGN STUDY, Report RAX-62-116, Volumes 1-10, Canadair Limited, Subsidiary of General Dynamics Corporation, Montreal, Canada, August 1962.

Anon., SYMPOSIUM ON TRI-SERVICE INDUSTRY V/STOL, Kirtland AFB, Blumfield, New Mexico, 1963, AD 337 666.

Thayer, W.P., THE XC-142A V/STOL ASSAULT TRANSPORT PROGRAM, Society of Experimental Test Pilots, 1963, pp 75-86.

This report describes the XC-142A V/STOL transport program which was conducted for the purpose of evaluating the military advantages to be derived from the development of VTOL capability. The general arrangement of the aircraft is shown. It is a 4-engine, high-wing, assault-transport aircraft with 7.5 ft by 7 ft by 30 ft cargo space and a design vertical takeoff weight of 37,500 lbs. The lifting principle used is tilt-wing, deflected slipstream. The wing can be tilted from 0 to 100 degrees relative to the fuselage; wing leading-edge slat and trailing-edge double-slotted flaps were programmed with wing incidence to prevent flow separation during transition and were fully retracted during hover and conventional flight. Figures show systems, controls, and test programs conducted on the aircraft, as well as problem areas which have been faced in its development and the major milestones for the program. The XC-142A was scheduled to make its first flight in July 1964. Hovering flights were scheduled for the Fall of 1964.

Anon., XC-142A VTOL TRANSPORT PROGRAM, Semiannual Report No. 3, Chance Vought Division of Ling-Temco-Vought Incorporated, Dallas, Texas, January-June 1963, AD 428 617.

Progress on the XC-142A program is reported. Numerous test programs were initiated and some completed, including the basic wind-tunnel tests of the 0.110-scale model and the control system bearing wear tests. The tooling effort reached its peak at the end of June 1963, with approximately 728 of the overall tooling tasks having been completed.

Anon., THE WFG-P POWERED-WING AIRCRAFT (TRIEBFLUGEL-FLUGZEUG WFG-P 16) Aerokurier, Vol. 7, July 1963, p 253.

A brief description of a proposed military VTOL two-seat aircraft is given. VTOL capability is provided by two tilttable 4-m-diam. propellers mounted at the tips of the

aircraft's stub wings. The wings remain in horizontal position during start and hover. The vertical-thrust component of the aircraft is sufficiently large to eliminate the need for wings. The latter serve only as mounts for the propellers.

Borst, H. V., DESIGN AND DEVELOPMENT CONSIDERATIONS OF THE X-19 VTOL AIRCRAFT, New York Academy of Sciences, Annals, Vol. 107, Art. 1, March 25, 1963, pp 265-279.

The design and development of the Curtiss-Wright X-19, a V/STOL aircraft, are discussed. The X-19 and the more conventional types of single-wing aircraft which use the tilt propellers are compared. Detailed treatment is given to hover longitudinal and lateral control, yaw control during hover, takeoff and hover performance, conversion, and conventional flight. It is shown that the tandem-wing, tilt-propeller X-19, when considered in its entirety, has good performance and handling characteristics as required for a V/STOL aircraft.

Anon., DEVELOPMENT OF THE U. S. ARMY VZ-2 (BOEING VERTOL-76) RESEARCH AIRCRAFT, Technical Report R219, Vertol Division of the Boeing Company, Morton, Pennsylvania, August 1963, AD 417 836.

The six-year development program of the U.S. Army VZ-2 research aircraft is presented. The technical feasibility of the tilt-wing concept was proven, and a sound basis was established for the development, design, and construction of a tilt-wing aircraft for specific missions. Although new problems were exposed, methods of solving them were indicated. The concentration of hovering controls exclusively within the propeller-wing assembly, by using full-span ailerons for yaw control, differential collective pitch for roll control, and monocyclic pitch for pitch control, will eliminate the need for yaw and pitch fans in future models. A more complete comparison and correlation of test results (NASA Flight Test, Contractor Flight Test, NASA Wind Tunnel and Princeton University Long Track Data) will provide comprehensive technical data for future designs.

Anon., THE BREGUET 941 STOL TRANSPORT, Interavia, Vol. 18, November 1963, pp 1756-1760.

Description of the performance characteristics and corresponding piloting requirements of the Breguet 941 are presented. Safety requirements of STOL transport aircraft and the controls of the Breguet 941 are considered, and piloting maneuvers regarding the takeoff and landing of the aircraft are discussed.



Anon., THE CURTISS-WRIGHT X-19 TILT PROP VTOL, Verti Flite, Vol. 9, December 1963, pp 2-10.

This article describes the design and fabrication criteria of the Curtiss-Wright X-19 tilt-prop VTOL twin-engine aircraft. The tandem wing X-19 has four tilting propellers mounted in nacelles at the wing tips, is of all-metal semimonocoque construction, and has a fully retractable landing gear. Listed are the performance data and characteristics released. The noise level prediction is for 60 db at 3,000 ft in front of the aircraft, which, at 350 knots, is less than a 7-second warning. The X-19 has an augmentation ratio of about 9:1 and a  $V_{max}$  of 400 kts at 20,000 ft. The control system, which is entirely mechanical, is very simple. Typical applications envisioned for the aircraft are air/sea rescue, utility transport, aerial fire support/escort, and medium transport/commercial transport. The two X-19s to be delivered will be used by the services to explore the problem areas common to all VTOLs and, specifically, to determine the compatibility of the tilt-prop concept with existing or proposed military requirements.

Fay, C.B., RECENT DEVELOPMENTS IN SIMPLIFYING AND IMPROVING THE TILT WING DESIGN, American Helicopter Society, Inc., Annual National Forum, 20th, Washington, D.C., Proceedings, New York, 1964, pp 161-183.

The approach, techniques, and results of analyses and test programs used by the Vertol Division of the Boeing Company to develop and improve the basic tilt-wing design are discussed. Efforts to extend the performance, maneuverability, and control characteristics are discussed in addition to the application of technological developments to specific requirements. Results indicate that tilt-wing technology has reached that stage of design and development where, with a simple and efficient design, it is now possible to meet specific military requirements.

Anon., THE CANADAIR CL-84 V/STOL AIRCRAFT, Interavia, Vol. 19, February 1964, pp 233-235.

The Canadair CL-84 V/STOL aircraft is comprised of a small-span rectangular wing rotatable through 90 degrees, two 1400-horsepower interconnected engines whose slipstreams blanket the wing, and a rotatable tail plane in conjunction with a tail rotor. Problems of stability and control arise mainly because of slipstream effects, and it is considered of primary importance to achieve a solution by aerodynamic means. An important factor is wing-tip location in relation to the propeller axes, and some wing-tip extension outboard is necessary to avoid premature flow separation. The tail rotor mounted in the pitch axis provides a fore-and-aft balancing moment in vertical flight and also contributes to lift. It is noted that control complexity is inevitable in V/STOL aircraft. However, in this case the rear rotor is the only additional element.

Anon., SUMMARY REPORT, CONVAIR MODEL 48 LIGHT ARMED RECONNAISSANCE AIRPLANE, Report GDC 64-029-1, Convair Division of General Dynamics Corporation, San Diego, California, March 1964.

Anon., PERFORMANCE DATA, CONVAIR MODEL 48 LIGHT ARMED RECONNAISSANCE AIRPLANE, Report GDC 64-029-7, Convair Division of General Dynamics Corporation, San Diego, California, March 1964.

Anon., STABILITY AND CONTROL DATA, CONVAIR MODEL 48 LIGHT ARMED RECONNAISSANCE AIRPLANE, Report GDC 64-029-8, Convair Division of General Dynamics Corporation, San Diego, California, March 1964.

Czinczenheim, J., and Edwards, J., THE AERODYNAMIC DESIGN AND FLIGHT DEVELOPMENT OF THE BREGUET 941 STOL AIRCRAFT (ETUDE AERODYNAMIQUE ET MISE AU POINT ENVOL DEL'AVION STOL BREGUET 941), Royal Aircraft Establishment, Farnborough, England, April 1964, AD 443 848.

The Breguet 941 short takeoff and landing aircraft is described. High lift coefficients are obtained by lowering the flaps and ailerons to deflect the slipstream from four interconnected propellers. The takeoff and landing techniques are discussed, and performance measurements are presented. Consideration is also given to the cruise performance. The flying qualities at low speed, with measurements of the static and dynamic stability and control, are compared with the AGARD requirements for V/STOL aircraft.

Bennett, W.S., XC-142A PERFORMANCE DATA REPORT 2-53310/4R942, Vought Aeronautics Division, Ling-Temco-Vought, Inc., Dallas, Texas, May 1964.

Gaebe, H.M., SOME IMPORTANT DESIGN CONSIDERATIONS ON XC-142A TRI-SERVICE V/STOL, Paper 64-281, American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., July 2, 1964.

Design and performance characteristics of the XC-142A all-weather cargo assault transport with VTOL capability are presented. Important dimensions and performance parameters are noted; and design solutions are considered for such problems as the noise over the exterior of the airplane, the range of propeller operating rpm, and propeller function at engine failure. The degradation of longitudinal static stability due to aeroelastic effects is shown. Because of the large tail, and large propellers located well out on the wing, the wing torsional deflections and tail support stiffness are significant contributors to loss of stability with speed. Graphs present the STOL capabilities of this aircraft and show the load-carrying flexibility that results from a basic VTOL requirement when answered by the tilt-wing propeller concept

Phillips, F.C., THE CANADAIR TILT-WING/DEFLECTED-SLIPSTREAM V/STOL PROTOTYPE PROGRAM, AGARD V/STOL AIRCRAFT, Canadair Limited, Subsidiary of General Dynamics, Montreal, Canada, 1964, pp 277-307.

This paper summarizes the early work which led to the choice of the tilt-wing/deflected-slipstream configuration for future design studies of V/STOL transport. Aircraft of this type are described. The significant research and development achievements are outlined: development of aerodynamic methods; construction and use of a mobile rig for open-air testing of V/STOL models; construction and use of a rig for static-thrust testing of developmental propellers; and flight simulation, using both a fixed-base simulator and a variable-stability helicopter. The original concept of the CL-84 was considered as a small research vehicle. Its evolution into a larger machine, intended as an operational prototype, is outlined. The relationship of the CL-84 to other V/STOL aircraft, with respect to performance and military roles is explained. The CL-84 prototype aircraft is described in detail. The makeup of the overall program is sketched, and various program elements are commented upon.

Borst, H.V., THE TRI-SERVICE X-19 V/STOL DESIGN CONSIDERATIONS AND FLIGHT TEST RESULTS - AGARD V/STOL AIRCRAFT, Pt. 1, Curtiss-Wright Corporation, Caldwell, New Jersey, September 1964, pp 309-338.

The X-19 is a V/STOL aircraft capable of high subsonic cruise speeds and high load-carrying capacity and range. The aircraft has fixed tandem wings with four tiltable propellers mounted at the wing tips. The propeller shaft angle is approximately 90 degrees at hover and 0 degrees at cruise. The propellers provide the necessary lift and control forces at the hover and slow-speed conditions as well as the thrust and a small component of lift at the high-speed cruise condition. The unusual configuration of the X-19 resulted from special considerations of the problem of hovering in low-speed flight and the importance of high hover efficiency with good performance at the cruise condition. The X-19 design concepts are discussed, and some of the special wind-tunnel data are presented. The special problems encountered with the unusual configuration of the X-19, which are complicated by the large speed range of the aircraft, are also discussed, and pertinent data are presented. The overall characteristics of the aircraft and the compliance with specifications in hover flight and cruise flight are presented. The existing characteristics of the aircraft are compared with the predicted performance and stability results, and any discrepancies are explained.

Anon., V/STOL AIRCRAFT, AGARDograph 89, North Atlantic Treaty Organization Advisory Group for Aeronautical Research and Development, Paris, France, September 1964.

Josephs, L. C., III., SURVEY OF SIGNIFICANT TECHNICAL PROBLEMS UNIQUE TO V/STOL ENCOUNTERED IN THE DEVELOPMENT OF THE XC-142A, Paper 64-775, American Institute of Aeronautics and Astronautics, Military Aircraft Systems and Technology Meeting, Washington, D.C., September 1964.

This paper discusses the development of a tilt-wing, deflected slipstream aircraft by Ling-Temco-Vought in a competition initiated by a Tri-Service V/STOL program. The XC-142A was developed to meet a mission involving the transport of 4 tons of payload for a radius of action of 200 nautical miles. The mission is indicated to be the same as the basic U.S. Army assault transport mission performed by a combination of the Caribou STOL transport and the Chinook helicopter. The XC-142A is described, and the aerodynamic problems that were encountered during its development are outlined, including transition, base drag, and ground effects. Various structural dynamics, dynamic response, and aircraft acoustics are discussed. Additional topics covered are flying qualities problems, propulsion system problems, and testing. Charts, graphs, and photographs illustrate the design mission, the aircraft configuration, and the performance of the XC-142A.

Josephs, L. C., III., SURVEY OF SIGNIFICANT TECHNICAL PROBLEMS UNIQUE TO V/STOL ENCOUNTERED IN THE DEVELOPMENT OF THE XC-142A, LTV Vought Aeronautics Division in AGARD V/STOL Aircraft, Ling-Temco-Vought, Inc., Dallas, Texas, September 1964.

The XC-142A is a tilt-wing, deflected slipstream configuration, powered by four GE T-64 engines driving 15-1/2-foot-diameter propellers. The technical problems discussed are grouped in the following areas: aerodynamic - transition, rate of descent, base drag, and ground effect problems; aeroelasticity - complexity of flutter problems and flutter model testing; flying qualities - the difficulty of establishing adequate design criteria for the hovering-transition region, all-weather flight requirements, longitudinal control problems affected by aeroelastic problems, and lateral/directional problems due to the severe cross-coupling inherent in the configuration; and propulsion - propeller vibration effects, particularly 2P and 4P, as well as transmission system dynamics which required the solution of equations involving as many as 50 degrees of freedom. The results of ground tests and flight tests are discussed.

Fling, G. K., THE XC-142A WING AND FLAP CONTROL SYSTEM, American Helicopter Society, Inc., New York, 1965.

A brief discussion of the flight controls of the tilt wing XC-142A aircraft is presented. The mechanization and operation of the wing and flap control system are described, and other control functions which are dependent on wing or flap positions are cited.

Phillips, F.C., THE CANADAIR CL-84 V/STOL TILT-WING PROTOTYPE, American Helicopter Society, Inc., New York, 1965, pp III 1-44.

The Canadair CL-84, a 6-ton, two-engined V/STOL aircraft of the tilt-wing, deflected-slipstream type, is described, and an outline of some of the reasoning that determined the airframe and equipment is given. The control system and the lift-propulsion system of the aircraft are described. Model testing and flight simulation activities are covered, especially as they relate to flying qualities. Component development and aircraft ground testing are discussed, with emphasis on problems encountered. Flight testing - past and future - is outlined and commented upon.

Shepard, T.W., Jr., THE XC-142A FLIGHT TEST PROGRAM, American Helicopter Society, Inc., New York, 1965, pp III 78-96.

The objectives of the XC-142A Flight Test Program are outlined. The philosophy used in planning the program is discussed, and the original plan is reviewed. Events leading up to first flight, first hover, and first transition are discussed. A comparison is then drawn between the plan and actual accomplishments. Accomplishments following initial conversion are then outlined. Program statistics are discussed, and the aircraft instrumentation system and data reduction methods are outlined. Some results obtained are presented and compared with predictions. Performance, structural demonstration, and system performance are discussed, but major emphasis is placed on flying qualities in the hover and transition flight regimes. Pilots' comments are included.

Longhurst, W.S., INITIAL DEVELOPMENT AND TESTING OF A TILT-WING V/STOL - Technical Review - Society of Experimental Test Pilots, Vol. 7, No. 4, 1965.

A study of the flight characteristics and test program of the CL-84 light V/STOL Army support vehicle is described. The testing consisted of model tests in a wind tunnel, a fixed-base hover rig test, and mobile rig tests. The aircraft was also subjected to ground testing on a tie-down rig which was capable of rotating into the wind. The first hover flights were performed from a large concrete pad, marked off in squares with two circles superimposed. After some piloting experience had been gained and the confidence level improved, pilot Cooper rating in the hovering mode was generally 2-1/2 to 3. Complete Stability Augmentation Systems were assessed and are rated at an average of 4-1/2 to 5. The general performance is shown.

Lusczek, J.J., Jr., and Martin, J.H., DESIGN CONCEPT OF A JET CLOSE SUPPORT AIRCRAFT (SUPER COIN), SAE Paper 650235, Society of Automotive Engineers, Inc., New York, April 1965.

Swan, G.H., TILT-WING DEFLECTED SLIPSTREAM AIRCRAFT, Astronautics and Aeronautics, Vol. 3, September 1965, pp 46-50.

The performance obtained by combining helicopter and fixed-wing aircraft technologies in tilt-wing deflected slipstream aircraft is discussed, including a review of the technical status of the configuration. The Ling-Temco-Vought XC-142A (four propellers) and the Canadair CL-84 (two propellers) are of this type. The basic propulsion and aerodynamic principles are: vertical flight from propeller static thrust, and a transition to conventional aerodynamic flights by use of a wing fully immersed in the propeller slipstream, fitted with programmed trailing-edge flaps to provide adequate stall margin. As the wing and propellers tilt down from the vertical during transition, the wing contributes substantially to the lift at extremely low speeds without stalling. This significantly reduces the power required with increase in airspeed from hover. Flying qualities are discussed in some detail. It is considered that improved propulsion-airframe system integration will make greater flexibility and reliability possible.

Johnston, G.W., SOME RECENT AERODYNAMIC ADVANCES IN STOL AIRCRAFT, Journal of Aircraft, Vol. 2, No. 5, September-October 1965, pp 390-397.

Irbetis, K., et al., STUDY OF CYCLIC PITCH PROPELLER APPLICATION TO THE CL-84 TILT WING V/STOL PROTOTYPE, ERR-CL-RAX-84-18, Canadair Limited, Subsidiary of General Dynamics, Montreal, Canada, October 1965.

Anon., NATIONAL V/STOL AIRCRAFT SYMPOSIUM (1st), Wright-Patterson AFB, American Helicopter Society, New York, November 1965, AD 634 548.

The X-22A airplane and its systems are described, including the special testing undertaken to prove these systems. Test progress and certain problem areas related to VTOL design are discussed. Test pilot participation in the pre-flight phases of the program and pilot preparation for first flights are described. Progress in ground test buildup to first flight is reported. Approach to first flight and development of V/STOL profiles are covered, and the demonstration program including military participation is outlined.

Nakaguchi, H. , STOL PERFORMANCE EMPHASIZED IN AIRCRAFT DESIGN WITH SPECIAL REFERENCE TO JAPANESE CONTRIBUTION, Paper 65-771, Aircraft Design and Technology Meeting, Los Angeles, California, American Institute of Aeronautics and Astronautics, Royal Aeronautical Society, and Japan Society for Aeronautical and Space Sciences, November 1965.

Possibilities of improving STOL aircraft performance, with special reference to Japanese experiments on a modified SAAB Safir single-engine monoplane, an experimental flying boat, and lightweight turbojet engines are presented. Increasing demands of STOL performance are discussed, with comments on certain difficulties which have been encountered. Airfoil sections and high lift devices, stability and control at low speed, and thrust tilting are considered. Modifications made to the SAAB Safir are outlined, and some results are described. Stall characteristics were found to be excellent. In the experimental flying boat, a unique feature is a new spray suppressor. High lift is achieved by a deflected slipstream combined with blown flaps and control surfaces. An experimental turbojet engine is briefly described.

Ransone, R.K. , and Jones, G.E. , XC-142A V/STOL TRANSPORT TRI-SERVICE LIMITED CATEGORY I EVALUATION, AFFTC, Report TR 65-27, Air Force Flight Test Center, Edwards AFB, California, 1966.

Anon. , DATA REPORT FOR THE OV-10A AIRPLANE, Report NA66H-47, Columbus Division, North American Aviation, Columbus, Ohio, 4 February 1966.

Kurdyla, N. , et al. , TILT-WING V/STOL UTILITY TACTICAL TRANSPORT AIRCRAFT CONCEPT, ERR-CL-RAZ-00-196, Canadair Limited, Subsidiary of General Dynamics Corporation, Montreal, Canada, November 1966.

Nishizaki, R.S. , ADVANCED TILT-WING V/STOL UTILITY TACTICAL TRANSPORT AIRCRAFT CONCEPT, ERR-CL-RAZ-00-200, Canadair Limited, Subsidiary of General Dynamics Corporation, Montreal, Canada, December 1966.

Anon. , CONFERENCE ON V/STOL AND STOL AIRCRAFT, NASA SP-116, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, 1966.

Davis, E.M. , Garrard, W.C. , Morrison, W.D. , and Scherrer, R. , NASA - LOCKHEED SHORT-HAUL TRANSPORT STUDY, Ames Research Center Conference on V/STOL and STOL Aircraft, National Aeronautics and Space Administration, Moffett Field, California, 1966.

Rolfe, V., et al., STUDIES IN SUPPORT OF THE CL-84 PROGRAM, ERR-CL-RAZ-00-207, Canadair Limited, Subsidiary of the General Dynamics Corporation, Montreal, Canada, 1967, p 86.

Anon., CL-84R AIR RESCUE VEHICLE, Report RAD 84-103, Vols. 1 and 2, Canadair Limited, Subsidiary of the General Dynamics Corporation, Montreal, Canada, March 1967.

Egerton, H.S., and Fitzpatrick, J.E., THE MODEL K-16B V/STOL RESEARCH AMPHIBIOUS AIRCRAFT, Kaman Aircraft Corporation, Bloomfield, Connecticut, March 1967.

Analytical and experimental research was conducted to investigate the use of a variable-camber, cyclic-controlled propeller, in combination with a partially tilting wing with full-span flaps, to permit V/STOL aircraft operation. These features were incorporated in a full-scale experimental aircraft designated the K-16B. This aircraft was used to explore the feasibility of a unified propulsion-control system designed to reconcile the conflict between the requirements of static thrust in hover and high-speed propeller efficiency, and to provide helicopter-type control in hover without the need for auxiliary control devices. This is accomplished by trailing-edge flaps on the blades of the propeller. Collective deflection of these flaps increases blade camber for high static thrust. The flaps are retracted in forward flight for a mean cruising-blade profile. Cyclic deflection of the flaps furnishes control moments in hover. The system was investigated on ground bench stands and in full-scale powered model tests of the K-16B.

Fluk, H., THE X-19 V/STOL TECHNOLOGY; A CRITICAL REVIEW, Curtiss-Wright Corporation, Wood-Ridge, New Jersey, May 1967, AD 826 319L.

The report contains a condensed description of the X-19 V/STOL technology. In Section I, the developments leading up to the X-19 program are reviewed. Sections II through VI are devoted to the propellers and the considerations involved in design. The radial force principle is postulated in Section II. Interference effects on the wings due to the propellers are discussed in Section III. The propeller aerodynamic design in hover and cruise is presented in Section IV. Section V is devoted to the structure and control mechanisms of the propeller. Section VI relates to the use of propellers as an airplane control device. The tandem wing principle is discussed in Section VII, covering stability, control, and drag. Section VIII is devoted solely to ground effects. The wind-tunnel research activity leading up to the X-19 is presented in Section IX. The structural loads in hover, transition, and cruise are discussed in Section X. Section XI presents information pertinent to landing procedures in hover or cruise in the event of power failure. A summary of the flight test program is given in Section XII.



Honaker, J.S., Chubboy, R.A., West, T.C., Davies, W., and Reschak, R.J., TRI-SERVICE EVALUATION OF THE CANADAIR CL-84 TILT-WING V/STOL AIRCRAFT, USAAVLABS Technical Report 67-84, U.S. Army Materiel Laboratories, Fort Eustis, Virginia, November 1967, AD 822 768L.

The Canadair CL-84 V/STOL aircraft was evaluated at Montreal, Canada, during the period 28 April to 29 August 1967. Thirty-three flights were flown, encompassing the hover, powered lifts, and aerodynamic flight regimes and speeds from 20 knots rearward to 230 kcas at 5,000 feet. The primary objectives of the evaluation were to determine the characteristics, capabilities, and limitations of the CL-84 aircraft and to assess the feasibility of using a CL-84-type aircraft for military missions, with emphasis on the search and rescue mission.

Anon., INTERNATIONAL CONGRESS OF SUBSONIC AERONAUTICS, New York Academy of Sciences, New York, April 1967.

Hendrickson, C.L., and Jones, G.E., XC-142A V/STOL TRANSPORT CATEGORY II PERFORMANCE EVALUATION, AFFTC-TR-68-21, Air Force Flight Test Center, Edwards AFB, California, October 1968, AD 842 810.

Approximately 27 productive flight test hours were flown on three aircraft, encompassing hover, vertical and short takeoffs and landings, climbs, descents, and cruise flight. The objective of this portion of the category II XC-142A evaluation was to obtain performance and problem area data for use in investigating the potential military application of the tilt-wing V/STOL transport aircraft.

Anon., ADVANCED V/STOL NAVAL AIRCRAFT STUDY, Vol. I - DESIGN AND ANALYSIS, Report LR-21049, Lockheed-California Company, Burbank, California, June 1968, AD 843 665L.

## **1.2 STUDIES OF SEVERAL TYPES OF V/STOL AIRCRAFT, UNUSUAL AND MISCELLANEOUS CONFIGURATIONS.**

Anon., A PROGRAM FOR THE AERODYNAMIC DEVELOPMENT OF VTOL AND STOL AIRCRAFT, REPORT ZA-274, Convair Division of General Dynamics Corporation, San Diego, California, May 1958.

Riebe, J.M., CONSIDERATION OF SOME AERODYNAMIC CHARACTERISTICS DURING TAKE-OFF AND LANDING OF JET AIRPLANES, NASA TN D-19, National Aeronautics and Space Administration, Washington, D.C., 1959.

In view of the transition from propeller-driven to jet transports, a study was made to determine some of the important differences in the aerodynamic characteristics during takeoff and landing. These differences were primarily associated with the absence of propeller slipstream over the wing and the attendant effects on lift. The considerations were limited only to lift-drag relations and did not include such possible related factors as noise, heating, foreign-matter ingestion, or ability to obtain thrust reversal. Speed and attitude may require closer attention for jet transports than for propeller-driven transports. Jet transports, by application of a system of lift augmentation, can have a lift-coefficient response with power on similar to that which has provided an operational margin for propeller-driven transports.

Schuck, G.I., AN ANALYSIS OF RESULTS FROM ARMY-SPONSORED VTOL RESEARCH AIRCRAFT, USATRECOM Technical Report 61-3, U.S. Army Transportation Research Command, Fort Eustis, Virginia, January 1961, AD 250 924.

Results of flight tests of the Bell XV-3, the Vertol VZ-2PH, the DOAK VZ-4Da, and the McDonnell XV-1 are summarized, with emphasis on the handling characteristics and flying qualities. The advantages and disadvantages of each type are discussed, along with the deficiencies inherent in the concept or in the design of the particular test bed. Possible ways of correcting deficiencies in future VTOL aircraft of these types are advanced.

Kelly, M.W., and Holzhauser, C.A., AERODYNAMIC CHARACTERISTICS OF SUBSONIC V/STOL TRANSPORT AIRPLANES, Paper 61-105-1799, Institute of the Aerospace Sciences, New York, 1961.

Anon., THE MARVEL PROJECT, THE MARVELETTE AIRPLANE BACKGROUND AND DESCRIPTION, Mississippi State University, State College, Mississippi, November 1963, AD 426 130.

A research project at Mississippi State University is reported in which an aerodynamic research aircraft, the Marvel, was designed to explore the problem areas

inherent in STOL fixed-wing aircraft. After several years of experimentation with modified off-the-shelf aircraft, it became evident that full evaluation of new STOL design techniques was severely limited by basic configurations of available aircraft and that an aircraft incorporating the latest techniques in its basic configuration should be designed and tested. As an interim step toward refinement of the Marvel design, a test bed aircraft, the Marvelette (XAZ-1), was designed, built, and flown. This report presents the history of the Marvel and a description of the Marvelette.

Norford, R. F., A NEW LOOK AT OLD DATA FOR THE CUSTER CHANNEL WING (A CURSORY INVESTIGATION OF STOL POTENTIAL), Naval Air Development Center, Johnsville, Pennsylvania, 1964, AD 458 804.

The Custer channel wing was subjected to a cursory investigation to determine its low-speed lift potential rather than its VTO capabilities. NACA tests made in 1953 were reviewed, and the results were compared to the calculated capabilities of a conventional wing and propeller combination using double-slotted flaps to deflect the slipstream for additional lift.

Stepniewski, W. Z., and Young, M. I., HELICOPTERS AND PROPELLER-TYPE VTOL AIRCRAFT IN THE LIGHT OF TECHNOLOGIES, Paper 650193, Society of Automotive Engineers, National Aeronautics Meeting and Production Forum, Washington, D. C., April 1965.

The aerodynamics and structures of pure and compound helicopters (including those with stoppable or stowable rotors) as well as propeller-type VTOL'S are examined. Trends in effective L/D ratio and flying speed and agility are discussed, along with other performance items. Aeroelastic, dynamic, and structural aspects of rotary-wing aircraft are considered, and specific limitations due to those phenomena are indicated. An interplay between design concepts and gross and empty weights is illustrated by the example of operations reflecting a combat mission. The totality of these considerations indicates that a 200-knot pure helicopter is feasible with the possibility of not exceeding cyclic stress and vibration levels of contemporary 150-knot helicopters. However, the effective L/D ratio at speeds of about 200 knots would be quite low. Compounding improves lift-to-effective drag ratio at such speeds, slightly, and moves the various aeroelastic barriers up to speeds of 250 knots. However, this leads to higher gross and empty weights. Simple stopping of rotors brings little improvement in the speed and range capabilities at the expense of still higher weights. Folding is more promising as far as the performance is concerned, and gross and empty weight penalties are no higher than in stopping. Retraction of the rotor improves aerodynamic cleanliness to the levels of propeller-type VTOL (tilt-wing) aircraft, but weight penalties are the highest. Because of its superior performance, high level of agility, and absence of fundamental aeroelastic limitations, the tilt-wing type is considered to be outstanding for certain combat missions.

Anon., THE AERODYNAMICS OF V/STOL AIRCRAFT, AGARDograph 126, North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Paris, France, May 1966.

Salveti, A., RESEARCHES ABOUT THE USE OF STOL AIRCRAFT IN CIVIL TRANSPORT AVIATION, SOME EXPERIMENTAL RESULTS ON A STOL AIRCRAFT MODEL, ICAS-Paper 68-07, Pisa University, Italy, Presented at the 6th Congress of the International Council of the Aeronautics Sciences, Munich, 9-13 September, 1968.

The technical economic evaluation of air transport over short hauls has been developed according to the following essential points: the provision of the request of transport; the definition of the technical economic and operative characteristics of the aircraft STOL and VTOL which are suitable to satisfy the request of transport; the examination of the problem of inserting the airports for the aircraft STOL and VTOL into the urban centers they must serve, and the economic evaluation of the system of air transport over short distances. A flying model of an aeroplane STOL with deflection of the slipstream and the boundary layer control has been realized and will be used for trial flight.

Harrah, R., OV-10 ROTATING CYLINDER FLAP STOL RESEARCH AIRCRAFT, North American Rockwell, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, Defense Documentation Center Summary Acc. No. NR-012649, 1968.

Design studies were performed on the hardware, mechanisms, and modifications to the OV-10A aircraft for incorporating rotating cylinder flaps, other high lift devices, and propeller interconnect. Modification or replacement of the propulsion and control systems was considered. Application for small STOL propeller-driven military or general aviation aircraft, with particular application to underdeveloped regions of the world is discussed. The design studies shall provide information for consideration in modifying the OV-10A aircraft with high lift systems and control capability to allow flight research investigations of a STOL aircraft capable of takeoff and landing in a distance of 500 feet.

### 1.3 COMPARATIVE STUDIES OF V/STOL AIRCRAFT

Anon., NASA CONFERENCE ON V/STOL AIRCRAFT, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1960.

Johnston, G.W., RECENT ADVANCES IN STOL AIRCRAFT DESIGN AND OPERATION, Paper 64-183, General Aviation Aircraft Design and Operations Meeting, Wichita, Kansas, American Institute of Aeronautics and Astronautics, May 1964.

This paper briefly reviews the results of some of the developments carried out by the de Havilland Aircraft Company of Canada in two broad areas: (1) basic STOL performances and (2) low-speed control and handling. In connection with basic STOL performance, the case for the classical STOL deflected-slipstream configuration and some of its limitations are reviewed. Some evolutionary improvements to this basic design approach are outlined. In addition, the possibility of replacing the classical propeller installation with a true jet STOL aircraft is briefly discussed. Improvements in low-speed control, both longitudinal and lateral, are discussed. The criteria of Anderson and Lean are reviewed, and some inherent limitations are noted. Finally, the flight-test results obtained with an experimental aircraft incorporating a modified longitudinal control system are discussed.

Brown, D.G., V/STOL TRANSPORTS AT HATFIELD, Flight International, Vol. 88, November 1965, pp 820-824.

Various V/STOL transport aircraft projects intended to bridge the gap between a C-130 (Hercules) airhead and a battle area are discussed. In general, it is considered that VTOL capability is necessary with STOL overtones. Because speed must be high, turbofan propulsion is proposed, which is said to give all the advantages of high productivity, flexibility, simplicity, economy of numbers, and low fleet costs. For STOL applications, the best solution was determined to be a turbofan aircraft with a high-aspect-ratio swept wing designed for high cruise efficiency. To achieve the airfield performance, the propulsion engine thrust should be deflected in the optimum manner and augmented by a high wing lift contribution from blown leading- and trailing-edge flaps. For VTOL's, it is considered that the jet lift solution with turbofan propulsion provides the best answer for both immediate and long-term requirements.

Phillips, F.C., V/STOL PITFALLS AND PAYOFFS, Canadian Aeronautics and Space Journal, Vol. 11, September 1965, 11 207-216.

Various types of VTOL aircraft are evaluated on the basis of stability and flight-handling characteristics. Short or vertical landing and takeoff imposes penalties in performance, first cost, and maintenance that tend to offset its desirability. The compound helicopter, consisting of a small wing and propeller together with the rotor, has a vibration problem at higher speeds; the tilt-wing type has stability problems when in the hover mode; and the tilt-propeller type suffers from lack of hover stability and mechanical complexity. The shrouded tilting-fan configuration is compact but mechanically of extreme complexity; it has relatively low maximum speeds. The fan-in-wing aircraft suffers from structural problems due to the large cutouts for the fans. The jet-ejector VTOL, a jet-propelled vehicle, is promising but relatively inefficient. It appears, however, that the tilt-wing VTOL can fill more of the needs of the military than any other type, while offering at the same time the greatest commercial potential.

Lichten, R. L., Graham, L. M., Wernicke, K. G., and Brown, E. L., A SURVEY OF LOW-LOADING VTOL AIRCRAFT DESIGNS, Paper 65-756, Aircraft Design and Technology Meeting, Los Angeles, California, American Institute of Aeronautics and Astronautics, Royal Aeronautical Society, and Japan Society for Aeronautical and Space Sciences, November 1965.

A comparative design study was made of the most promising low-disk-loading VTOL concepts which combine the vertical takeoff and landing capability of the helicopter with the high speed and efficient cruise of the aircraft. The VTOL concepts examined were: slowed-rotor compound, stopped-rotor, stowed-rotor, tilt-prop rotor, tilt-wing, and trail-rotor. These aircraft were designed for high speed, low-altitude transport missions requiring a payload of at least 3,000 lb. Each configuration has the same installed power, has a lifting rotor disk loading of 10 lb/ft<sup>2</sup>, and hovers out of ground effect at 6,000 ft on a 95° F day at design gross weight. Transport effectiveness comparisons of the six configurations show that the tilt-prop rotor, tilt-wing, and trail-rotor have useful loads, productivities, and payload delivery efficiencies considerably greater than those of the other types. The tilt-prop rotor configuration has the highest transport effectiveness of the six configurations examined. In comparison to an equivalent transport helicopter, the better low-disk-loading VTOL types cruise at about double the speed and provide more than double the mission effectiveness; in comparison to an equivalent high-disk-loading tilt-wing design, the better low-disk-loading types cruise at a slightly lower speed but provide double the mission effectiveness. The low-disk-loading VTOL's can perform longer range missions by cruising at 20,000 ft, which increases the sea level payload delivery efficiency by 80% and the range by 60%.

Howard, G.J., and Ulinik, H.D., A COMPARATIVE STUDY OF PROPELLER DRIVEN VTOLS FOR THE TRI-SERVICE FOUR TON REQUIREMENTS, National V/STOL Aircraft Symposium, 1st, Wright-Patterson AFB, Ohio, November 3-4, 1965, Proceedings, American Helicopter Society, New York, 1965, pp 182-96.

A comparative design study is presented of four fundamentally different VTOL types which use propellers as their primary cruise system. The Tri-Service four-ton mission forms the basis against which a quad tilt propeller, tilt prop/rotor, and two direct lift jets (one with cruise thrust vectoring and the other without) are compared. Results of a parametric analysis, based on current state-of-the-art capabilities, are discussed, with particular emphasis placed on mission performance; evaluations are made on the basis of productivity and vehicle empty weights, as these parameters are considered to be good indices of system costs. In addition, some design problems are discussed in the context of current technology. The direct lift jet with cruise thrust vectoring is found to be the design concept possessing the highest mission effectiveness.

Anon., V/STOL AIRCRAFT, National Aeronautics and Space Administration, Washington, D.C., NASA Facts, Vol. 2, No. 3, 1966.

As part of its educational service program, NASA has prepared a fact sheet on V/STOL aircraft concepts and configurations. The five VTOL concepts — tilt rotor, deflected slipstream, tilt duct, deflected jet, and tilt wing — are presented. The VTOL propeller, ducted fan, and jet configurations as well as the flight research programs being conducted on various V/STOL lift-propulsion concepts, are briefly discussed.

Marsh, K.R., STUDY ON THE FEASIBILITY OF V/STOL CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT, LTV Corporation, NASA CR-670, National Aeronautics and Space Administration, Washington, D.C., 1967.

A feasibility study has been performed in which 18 airplanes have been developed around 3 V/STOL propulsion concepts, 4 V/STOL operational capabilities, and 3 passenger-load capabilities. Each of the airplanes developed has been optimized to give a near minimum direct operating cost on the design stage length of 500 miles within the constraints of its selected V/STOL propulsion system, V/STOL operational capability, and passenger load capability. This study has found the turboprop V/STOL airplanes to have only modest cruise speed capabilities, relatively low direct operating costs, and comparatively light weights; and there are considerable data to guide the designer of turboprop V/STOL aircraft. The fan-in-wing V/STOL airplanes have a relatively high cruise speed, high direct operating costs, and high propulsion system plus fuel weights and hence gross weights. There are considerable data available to the designer of fan-in-wing airplanes, though not as

voluminous or complete as for the turboprop. The propulsive wing V/STOL airplanes have high subsonic cruise speed capabilities, low direct operating costs, and relatively light weights; but there are only limited data to guide the designer of such aircraft.

Stickle, G.W., and Copp, M.R., SOME CONSIDERATIONS ON THE MID-TERM REPORTS OF THE VERTICAL LIGHT TRANSPORT STUDIES (U), TAC-OA-WP-135, Tactical Air Command Langley AFB, Virginia, Office of Operations Analysis, May 1967. (Confidential)

Fry, B.L., and Zabinsky, J.M., FEASIBILITY OF V/STOL CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT, NASA CR-743, National Aeronautics and Space Administration, Washington, D.C., May 1967.

The results of a study of VTOL and STOL short-haul transports are presented. Five VTOL and two STOL aircraft were analyzed to determine those most suitable for commercial short-haul operation and the research required to bring them to full operational status. The VTOL concepts studied were the tilt wing, jet lift, stowed-rotor helicopter, and tip-turbine lift fan aircraft. The STOL types were the fan-in-wing and the high-lift turbofan. The study covered airplane design, operational techniques, noise and public acceptance, acquisition cost, direct operating cost, technical risk, and research requirements. The results of the study show that the turbofan STOL, tilt-wing VTOL, lift-fan VTOL, and jet-lift VTOL are the most promising concepts. Furthermore, if solutions can be found to the noise-suppression problem for the jet-propulsion types, they can all be brought to operational status in 1970 to 1975 time period. The direct operating costs of V/STOL aircraft are potentially no higher than those of conventional short-haul jet aircraft over 500-mile stage lengths, and will be lower than the operating costs of present turbine helicopters for very short trips down to 25 miles.

Schmidt, R.C., COMPOSITE V/STOL UTILITY/LOGISTICS AIRCRAFT, SPEED VERSUS PAYLOAD AND PRODUCTIVITY, Report BRL-MR-1850, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, 1967, AD 819 290.

An analysis of the performance of turbine-powered tilt-wing and tilt-propeller V/STOL aircraft was undertaken by the U.S. Army Ballistic Research Laboratories (BRL) to determine the effect of the designed maximum continuous cruise speed upon payload and productivity. Propulsion system performance was calculated for 81 permutations of propeller parameters but with an arbitrarily selected modern developmental turboshaft engine. Gross weight ranged from 8,000 to 14,000 pounds. Operating boundaries of speed versus gross weight were established from which four vehicles were selected for the payload and productivity analysis. Two utility and logistics-type missions producing definite speed and payload trends were used for the evaluation.



**Anon. , ASPECTS OF V/STOL AIRCRAFT DEVELOPMENT, AGARD Report 13, Advisory Group for Aerospace Research and Development, Paris, France, September 1967, AD 669 767.**

The report consists of survey papers concerning aerodynamic problems, propulsion problems, and the problems of development of V/STOL aircraft from the flight mechanics aspect.

**Anon. , STUDY OF THE FEASIBILITY OF V/STOL CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT, NASA CR-902, Lockheed-California Company, National Aeronautics and Space Administration, Washington, D.C., October 1967.**

The design, operational, and economic aspects of several different VTOL and STOL aircraft configurations were evaluated to determine which of the aircraft are most promising for development into successful commercial short-haul transports. Aircraft were designed to carry 60 passengers for a distance of 500 statute miles, and other guidelines were established to assure that the vehicles would be studied on a common basis. The STOL aircraft included the deflected slipstream, jet flap, and fan-in-wing configurations. The VTOL aircraft included tilt-wing, tilt-rotor, stopped-rotor and lift/cruise fan concepts. Parametric and detail design studies were made to provide a basis for selecting the optimum design characteristics of each concept. Computers were used to map vehicle weights, dimensions, performance, and direct operating costs as functions of the design parameters. Several designs were selected from the initial data for further analysis, including development of 120-passenger configurations and more detailed design studies. The sensitivities of performance, weight, and cost to design changes and differences in mission rules were also examined. The basic characteristics of the final vehicles are shown.

**Marsh, K.R. , ADDITIONAL STUDIES ON THE FEASIBILITY OF V/STOL CONCEPTS FOR SHORT-HAUL TRANSPORT AIRCRAFT, NASA CR-670(01), Ling-Temco-Vought Corporation, National Aeronautics and Space Administration, Washington, D.C. , December 1967.**

**Stickle, G.W. , CRITICAL FACTORS AFFECTING AIRCRAFT DESIGNED FOR INTRATHEATER AIRLIFT MISSIONS (U), TAC-OA-WP-68-6, Tactical Air Command, Langley AFB, Virginia, Office of Operations Analysis, August 1968, AD 3935611. (Confidential)**

**Brewer, J.D. , NASA RESEARCH ON PROMISING V/STOL AIRCRAFT CONCEPTS, National Aeronautics and Space Administration, Washington, D.C. , 1968.**

Design concepts, contractor studies, and operational requirements are reviewed in relation to the NASA research program on V/STOL aircraft. The different aircraft concepts that were investigated are noted, and the relative merits as well as costs of some are discussed. Studies indicate the need for advanced systems at the terminal area for aircraft guidance to improve control and safety and to reduce time of instrument-flight conditions. The NASA program includes the short takeoff and landing short-haul transport, the vertical takeoff and landing transport, the advanced helicopter, and the VTOL tactical fighter. Wind-tunnel tests that have used a rotating cylinder flap and an augmentor wing to achieve greater lift and zero visibility landing operational capability as well as noise are discussed.

#### **1.4 FLIGHT STUDIES OF V/STOL AIRCRAFT AND CONVENTIONAL AIRCRAFT**

**Zaloveik, J. A., Wetmore, J. W., and von Doenhoff, A. E., FLIGHT INVESTIGATION OF BOUNDARY-LAYER CONTROL BY SUCTION SLOTS ON AN NACA 35-215 LOW-DRAG AIRFOIL AT HIGH REYNOLDS NUMBERS, NACA Advance Report 4B29, National Advisory Committee for Aeronautics, Washington, D. C., February 1944.**

The effectiveness of suction slots as a means of extending the laminar boundary layer has been investigated in flight at high Reynolds numbers on an NACA 35-215 airfoil. The test panel, having a chord of 204 inches and an average span of 90 inches, was mounted on the left wing of a Douglas B-18 airplane. The upper surface of the test panel was provided at first with nine spanwise slots and later with eight additional slots, all located between 20 and 60 percent of the chord. Tests were made with normal operation of the airplane engines over a range of service indicated airspeed from 147 to 216 miles per hour, which gave a range of airplane lift coefficient from 0.41 to 0.19 and a corresponding range of Reynolds number from  $21.7 \times 10^6$  to  $30.8 \times 10^6$ .

**Tosti, L. P., and Davenport, E. E., HOVERING FLIGHT TESTS OF A FOUR-ENGINE TRANSPORT VERTICAL TAKE-OFF AIRPLANE MODEL UTILIZING A LARGE FLAP AND EXTENSIBLE VANES FOR REDIRECTING THE PROPELLER SLIPSTREAM, NACA TN 3440, National Advisory Committee for Aeronautics, Washington, D. C., 1955.**

**Rolls, L. S., and Innis, R. C., A FLIGHT EVALUATION OF A WING-SHROUD-BLOWING BOUNDARY-LAYER CONTROL SYSTEM APPLIED TO THE FLAPS OF AN F9F-4 AIRPLANE, NACA RM A55K01, National Advisory Committee for Aeronautics, Washington, D. C., 1955.**

As a portion of the general research program on the use of boundary-layer control to improve the maximum lift characteristics of airplane wings, the Bureau of Aeronautics loaned the Ames Aeronautical Laboratory of the NACA an F9F-4 airplane to evaluate a high-energy-blowing boundary-layer-control system in flight. The high-energy-blowing boundary-layer-control system was installed in the F9F-4 airplane by the Grumman Aircraft Engineering Corporation on contract with the Bureau of Aeronautics. A series of test flights was made to measure the lift and drag variations with changes in angle of attack for the flap and gear both up and down and for blowing both on and off. The test data indicated that the boundary-layer-control system increased the maximum lift coefficient in the approach configurations from 1.98 to 2.32. An evaluation of the airplane by four research pilots at the Ames Laboratory indicated an average reduction of 10 knots in the

approach speed by the use of the boundary-layer-control system. Calculations were made to evaluate the performance capabilities of the airplane with boundary-layer control in the takeoff, catapult, approach, and landing configurations.

Cooper, G. E., and Innis, R. C., EFFECT OF AREA-SUCTION TYPE BOUNDARY-LAYER CONTROL ON THE LANDING-APPROACH CHARACTERISTICS OF A 35 DEGREE SWEEP-WING FIGHTER, NACA RM A55K14, National Advisory Committee for Aeronautics, Washington, D. C., February 1956.

This report presents results of evaluation flights of F-86 series aircraft equipped with two types of boundary-layer control differing significantly with regard to the type of lift increment produced. In one case, application of boundary-layer control to the wing leading edge increased maximum lift coefficient,  $C_{L_{max}}$ , significantly by delaying stall to higher angles, but it provided no change in lift at a given attitude. In contrast, application of boundary-layer control to the trailing-edge flaps increased the flap lift increment at attitudes below  $C_{L_{max}}$ , but resulted in only a small increase in  $C_{L_{max}}$ . The report presents the comments of 16 Air Force, Navy, contractor, and NACA pilots as to the reasons for their choice of minimum, comfortable approach speed on the several configurations tested. These pilots' opinions are analyzed in relation to the characteristics of the airplanes in an attempt to isolate the aerodynamic factors of primary importance in establishing landing-approach speeds.

Anderson, S. B., Quigley, H. C., and Innis, R. C., FLIGHT MEASUREMENTS OF THE LOW-SPEED CHARACTERISTICS OF A 35 DEGREE SWEEP-WING AIRPLANE WITH BLOWING-TYPE BOUNDARY-LAYER CONTROL ON THE TRAILING EDGE FLAPS, NACA RM A56G30, National Advisory Committee for Aeronautics, Washington, D. C., October 1956.

Tests have been conducted to determine the flight characteristics of an F-86 airplane equipped with a blowing-type boundary-layer-control installation on the trailing-edge flaps. Included in this study are the pilots' evaluation of the operational use of the boundary-layer-control system. The effectiveness of the flap was determined in conjunction with slatted leading edges and an inflatable rubber boot on the leading edge. Measurements were made of the lift, drag, and flow requirements. Performance computations were made for takeoff, climb, and landing. The results of the flight tests are compared with those of full-scale wind-tunnel tests of a similar type installation, and with those of flight tests of a wing-shroud blowing system of an F9F-4 airplane.

Anderson, S. B. , Faye, A. E. , and Immis, R. C. , FLIGHT INVESTIGATION OF THE LOW-SPEED CHARACTERISTICS OF A 35 DEGREE SWEPT-WING AIRPLANE EQUIPPED WITH AN AREA-SUCTION EJECTOR FLAP AND VARIOUS WING LEADING-EDGE DEVICES, NACA RM A57G10, National Advisory Committee for Aeronautics, Washington, D. C. , September 1957.

Tests have been conducted to determine the flight characteristics of an F-86F airplane equipped with an area-suction-type boundary-layer control installation on the trailing-edge flaps. Ejector pumps enclosed within the flaps were used for suction. Flap lift increments were determined in conjunction either with a slatted leading edge or with an inflatable rubber boot on the wing leading edge. Measurements were made of the lift, drag, and engine bleed-air requirements. The results of the flight tests are compared with those of flight tests of a blowing-flap-type boundary-layer control system on the same airplane.

Tosti, L. P. , FLIGHT INVESTIGATION OF THE STABILITY AND CONTROL CHARACTERISTICS OF A 1/4-SCALE MODEL OF A TILT-WING VERTICAL-TAKE-OFF-AND-LANDING-AIRCRAFT, NASA Memo 11-4-58L, National Aeronautics and Space Administration, Washington, D. C. , 1958.

Thomas, L. P. , III, A FLIGHT STUDY OF THE CONVERSION MANEUVER OF A TILT-WING VTOL AIRCRAFT, NASA TN D-153, National Aeronautics and Space Administration, Washington, D. C. , 1959.

Stepniewski, W. Z. , and Dancik, P. J. , FLIGHT EXPERIMENTS WITH THE TILT-WING AIRCRAFT, Paper 59-8, Institute of Aerospace Sciences, February 1959.

Gustafson, F. B. , Pegg, R. J. , and Kelley, H. L. , AERODYNAMIC OBSERVATIONS FROM FLIGHT TESTS OF TWO VTOL AIRCRAFT, NASA Conference on V/STOL Aircraft, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, November 1960.

Gyorgyfalvy, D. , FLIGHT INVESTIGATION OF LEADING-EDGE SUCTION BOUNDARY-LAYER CONTROL OF A LIAISON TYPE STOL AIRCRAFT, Research Report 31, Mississippi State University, State College, Mississippi, 1961.

Quigley, H. , Koenig, C. , and David G. , A FLIGHT STUDY OF THE DYNAMIC STABILITY OF A TILTING-ROTOR CONVERTIPLANE, NASA TN D-778, National Aeronautics and Space Administration, Washington, D. C. , 1961.

A flight investigation was conducted to determine the effect of blade flapping on the stability and control of the XV-3 Convertiplane in cruise and high speed flight. The results of the study indicated that the inplane forces on the prop-rotors due to the blade flapping associated with airplane angular rates were in a direction to produce negative damping moments on the airplane. As a result of these inplane forces, the damping ratio of the longitudinal short period and lateral-directional oscillations approached zero at the maximum airspeed of the test airplane.

Immis, R. C., and Quigley, H. C., A FLIGHT EXAMINATION OF OPERATING PROBLEMS OF V/STOL AIRCRAFT IN STOL-TYPE LANDING AND APPROACH, NASA TN D-862, National Aeronautics and Space Administration, Washington, D. C., 1961.

Tosti, L. P., RAPID TRANSITION TESTS OF A 1/4-SCALE MODEL OF THE VZ-2 TILT-WING AIRCRAFT, NASA TN D-946, National Aeronautics and Space Administration, Washington, D. C., 1961.

Pegg, R. J., SUMMARY OF FLIGHT TEST RESULTS OF THE VZ-2 TILT-WING AIRCRAFT, NASA TN D-989, National Aeronautics and Space Administration, Washington, D. C., 1962.

Pegg, R. J., FLIGHT-TEST INVESTIGATION OF AILERONS AS A SOURCE OF YAW CONTROL ON THE VZ-2 TILT-WING AIRCRAFT, NASA TN D-1375, National Aeronautics and Space Administration, Washington, D. C., 1962.

Kelley, H. L., TRANSITION AND HOVERING FLIGHT CHARACTERISTICS OF A TILT-DUCT VTOL RESEARCH AIRCRAFT, NASA TN D-1491, National Aeronautics and Space Administration, Washington, D. C., November 1962.

Drinkwater, F. J., III, and Turner, H. L., SOME FLIGHT CHARACTERISTICS OF A DEFLECTED SLIPSTREAM V/STOL AIRCRAFT, Ames Research Center, NASA TN D-1891, National Aeronautics and Space Administration, Moffett Field, California, July 1963.

Kidwell, J. C., TAKEOFF AND LANDING CAPABILITIES OF THE CARIBOU CV-23 AIRCRAFT ON UNPREPARED SURFACES, USAATA Technical Report 63-4, U.S. Army Aviation Test Activity, Edwards AFB, California, September 1963, AD 440 406L.

Tests were conducted to determine the performance of CV-2B airplanes when using surfaces and environments similar to those encountered during the Air Force Project Rough Road Alpha. The tests indicate that the takeoff and landing

performance of the CV-2B airplane, when operating at its maximum gross weight of 28,500 lbs, was better than that of the C-130B and the C-123B, even when these airplanes were operating near minimum practical gross weights. The takeoff and landing performance of the CV-2B operating at maximum gross weight was either equal to or better than that of the JC-130B, the NC-130B, and the YC-123H. The CV-2B equipped with reversing propellers demonstrated landing performance that was considerably better than that of any of the airplanes tested during the Air Force Project Rough Road Alpha.

Neal, B., THE EFFECT OF THRUST VARIATION WITH FORWARD SPEED ON THE STOL PERFORMANCE OF AN OVERLOADED TILT-WING VTOL AIRCRAFT, NAE LR-373A, National Aeronautical Establishment, National Research Council, Ottawa, Canada, 1963.

Henshaw, C.J., and Schiele, J.S., BREGUET 941.01 (BR 941) LIMITED FLIGHT EVALUATION, AFFTC TDR 64-7, Air Force Flight Test Center, Edwards AFB, California, 1964, AD 440 176.

This report presents the results of a limited flight-test evaluation of the Breguet 941 prototype aircraft. The objectives of the evaluation were to collect limited performance data and qualitative stability and control data, and to evaluate the BR 941 during STOL operation both on and off the runway. The cross-shaft-driven propellers used on the BR 941 airplane provided safe operation and created pilot confidence at the low flight speeds required for STOL operation. The control power available, even at minimum flying speed, was more than adequate about all three axes. The propeller cross-shaft design concept of the BR 941 should be a primary consideration for all future similar V/STOL vehicles. Aircraft longitudinal static stability was essentially neutral in all configurations tested. Center-of-gravity location had very little effect on longitudinal static stability. The maximum speed of the test aircraft, using normal rated power, was only 215 KTAS at 10,000 feet. The lack of cabin pressurization could restrict the use of the aircraft. The aircraft appeared to be easily maintained.

Quigley, H.C., Innis, R.C., and Holzhauser, C.A., A FLIGHT INVESTIGATION OF THE PERFORMANCE, HANDLING QUALITIES, AND OPERATIONAL CHARACTERISTICS OF A DEFLECTED SLIPSTREAM STOL TRANSPORT AIRPLANE HAVING FOUR INTERCONNECTED PROPELLERS, NASA TN D-2231, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, 1964.

The Breguet 941, a large four-engine aircraft having full-span triple-slotted, trailing-edge flaps and interconnected propellers, was studied to gain further

information on the flight and operational characteristics of typical STOL aircraft. The Breguet 941 had good STOL performance, with the capability of making a landing approach with a glide slope of about 8 degrees at an airspeed of less than 60 knots. The takeoff and landing distances over 35- and 50-ft obstacles, respectively, were less than 1,000 feet. The STOL handling qualities of the airplane were rated satisfactory except for longitudinal static stability and the lateral-directional static and dynamic stability, which were rated acceptable. Because of a propeller interconnect feature, the airplane was considered to be safe to fly at the low airspeeds required for STOL performance.

Schwarz, F., and Wuest, W., FLIGHT TESTS OF A PROTOTYPE DO 27 WITH BOUNDARY-LAYER SUCTION TO INCREASE MAXIMUM LIFT, *Zeitschrift fuer Flugwissenschaften*, Vol. 12, March 1964, pp 108-120. In German.

Cornish, J. J., SOME AERODYNAMIC AND OPERATIONAL PROBLEMS OF STOL AIRCRAFT WITH BLC, Paper 64-193, American Institute of Aeronautics and Astronautics, General Aviation Aircraft Design and Operations Meeting, Wichita, Kansas, May 1964.

This paper summarizes some of the findings of tests made on conventional aircraft modified to use the technique of boundary-layer control by suction to attain STOL flight. From the flight tests conducted on these vehicles, several characteristic problems typical of this method of increasing lift have become apparent. The methods used to alleviate or avoid the particular problem are described. Flight test results from a number of aircraft using suction boundary-layer control for lift augmentation are examined and compared. It is concluded that the attainment and use of high lift coefficients have emphasized several shortcomings of currently used aerodynamic theories and have brought into prominence the interference effects of some aircraft components not ordinarily considered at relatively low lift coefficients.

Johnston, G. W., MODULATED THRUST TO IMPROVE STOL AIRCRAFT PERFORMANCE (A FLIGHT TEST EVALUATION), AGARD, in AGARDograph 89 V/STOL Aircraft, Part I, September 1964.

Czinczenheim, J., and Joyeuse, G., TEST FLIGHTS OF 940 AND 941 BREGUET AIRCRAFT (ESSAIS EN VOL DES AVION BREGUET, 940 ET 941) IN AGARD V/STOL Aircraft, Part I, Advisory Group for Aeronautical Research and Development, Paris, France, September 1964, pp 339-368.

A brief description is given of the main characteristics of the two airplanes: mechanical interconnection, countershafts and transmission gearboxes, reducers, and multiple uses of the propellers as high lift flaps and controls. Investigations



and preliminary tests were conducted prior to flight testing: (1) conventional wind-tunnel tests; (2) simulator tests, free-flight models; (3) mechanical full-scale bench testing, including propulsion system development and engine failure investigation; (4) piloting techniques and takeoff procedure, including selection of takeoff safety speed; (5) engine and propeller failure; (6) capability for tight turns with little bank and spiral trajectory; (7) takeoff stability and control; (8) piloting technique and landing procedure; and (9) use of the incidence angle as a main piloting parameter (BIT) with means for correcting the glide slope - by single lever, air-brakes, and wide visibility angles, steep and shallow glide paths, touchdown accuracy, and landing aids. Advantages of a low-speed takeoff and approach in poor visibility conditions were shown. The problem of using full throttle again during landing was investigated. Flight properties of STOL aircraft during approach were observed. Use of television for flow visualization studies was considered. The STOL aircraft is compared with VTOL and conventional aircraft.

Newsom, W.A., and Kirby, R.H., FLIGHT INVESTIGATION OF STABILITY AND CONTROL CHARACTERISTICS OF A 1/9-SCALE MODEL OF A FOUR-PROPELLER TILT-WING V/STOL TRANSPORT, NASA TN D-2443, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, September 1964.

The tests included hovering flights in and out of ground effect, and level flight and descent conditions in the transition speed range. No artificial stabilization was used in any of the tests. Even though the model was statically and dynamically unstable for many of the flight-test conditions, it could generally be controlled and maneuvered easily. The descent tests showed that the configuration had at least a 6° descent capability with no adverse effects, and that an additional 3° or 4° of descent angle was available before completely unacceptable flying qualities were encountered as a result of wing stalling. In all flight regions, the minimum total control powers found to be satisfactory in the model flight tests were less than the control powers planned for the full-scale aircraft.

Anon., EVALUATION BREGUET 941 AIRCRAFT (McDonnell 188), TR 64-45, Tactical Air Command, Langley, AFB, Virginia, October 1964, AD 449 443.

The Breguet 941.01 (BR-941), a prototype aircraft, was evaluated for possible use as a STOL assault transport in the special air warfare environment. The aircraft was flown 125 hours, and 200 landings were made. Of these, 54 landings were accomplished on off-runway areas at gross weights up to the maximum allowable. The unusual features of the BR-941 are well matched to provide a true STOL capability with a high degree of safety. The aircraft is simple and easy to fly, and

it has excellent cargo loading features. In-flight cargo delivery features were not evaluated because of the present restriction on ramp door operation in flight. This particular prototype aircraft is not compatible with the 463L system.

Fry, B. L., LOW-SPEED, AERODYNAMIC FLIGHT BOUNDARIES AND CONTROL ASPECTS OF TILT-WING AIRCRAFT, New York, American Helicopter Society, 1965.

The tilt-wing-aircraft approach to achieving satisfactory levels of deceleration and rate of descent without encountering wing stall, and to obtaining sufficient control power without adding complexity and weight is discussed. The results of the aerodynamic test programs associated with solution of these problems are also given. The effects of leading-edge devices, flaps, fences, propeller position and direction of rotation, and center-section configurations on the wing stall characteristics and related transition performance are discussed. Tuft studies used to develop criteria for limiting flight conditions are substantiated by comparison of model and flight test results. The results of a hover yaw-control investigation and of a wind-tunnel test of a tilt-wing model with monocyclic propellers are also presented. Pitch control with cyclic propellers does not adversely affect transition performance, and spoilers are shown to be effective for hover yaw control.

Pegg, R. J., Kelley, H. L., and Reeder, J. P., FLIGHT INVESTIGATION OF THE VZ-2 TILT-WING AIRCRAFT WITH FULL-SPAN FLAP, NASA TN D-2680, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1965.

This report presents some of the results of a full-scale flight investigation on the VZ-2 tilt-wing research aircraft following several modifications that changed its flying qualities and its aerodynamic characteristics. The primary change was the addition of a full-span, single-slotted flap that was programmed with wing-tilt angle or could be independently operated by the pilot. Other changes were a reduction in the roll-control sensitivity, the provision of full-span ailerons for yaw control in addition to the yaw an, and a drooped leading edge on the wing. The results include the effect of the full-span flap on the rate-of-descent capability, measurements of control axes in hover and low-speed flight, and operational and aerodynamic aspects of STOL problems of the flapped tilt wing near the ground.

Finnestead, R. L., and Antoniou, N. N., PERFORMANCE TESTS OF THE CV-2B AIRPLANE, USAATA 63-74, U. S. Army Aviation Test Activity, Edwards AFB, California, June 1965, AD 467 490L.

Engineering flight tests were conducted to evaluate the performance and flying qualities of the CV-2B airplane, with special emphasis on takeoff and landing

performance in the short takeoff and landing (STOL) configuration. Tests were conducted at test sites in Bakersfield, Edwards, Bishop, Eldorado County Airport, and Coyote Flats, California. The program consisted of 120 hours of flight testing and was accomplished during the period 25 August 1963 through 20 January 1964. The test airplane (U.S. Army S/N 62-4175) was modified from a CV-2 to a CV-2B by the incorporation of the following major changes: (1) STOL operation capabilities were increased from 26,000 to 28,500 pounds, and (2) reverse pitch propellers were installed.

Hickey, D.H., and Cook, W.L., CORRELATION OF WIND-TUNNEL AND FLIGHT-TEST AERODYNAMIC DATA FOR FIVE V/STOL AIRCRAFT, AGARD Report 520, Advisory Group for Aerospace Research and Development, Paris, France, October 1965.

The five aircraft tested represent a wide variety of V/STOL concepts. Correlation between the wind-tunnel and flight test aerodynamic results is generally good when wind-tunnel wall corrections are omitted; in some cases, wall corrections are shown to degrade the correlation. The aircraft and wind-tunnel geometry are related to model-tunnel sizing parameters and a VTOL lift parameter, in order to establish tentative sizing criteria for V/STOL wind-tunnel testing with small wall effects.

Clark, D.B., and Head, M.R., FLIGHT EXPERIMENTS ON SUCTION FOR HIGH LIFT, Paper 65-750, American Institute of Aeronautics and Astronautics, Royal Aeronautical Society, and Japan Society for Aeronautical and Space Sciences, Aircraft Design and Technology Meeting, Los Angeles, California, November 15-18, 1965.

Clark, D.B., Roberts, S.C., and Smith, M.R., FLIGHT TEST EVALUATION OF A DISTRIBUTED SUCTION HIGH-LIFT BOUNDARY LAYER CONTROL SYSTEM ON A MODIFIED L-19 LIAISON AIRCRAFT, Aerophysics Research Report 66, Mississippi State University, State College, June 1966.

Hickey, D.H., COMPARISON DATA FROM WIND TUNNEL AND FLIGHT TESTS OF THE SAME STOL AND V/STOL AIRCRAFT, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, Defense Documentation Center Summary Acc. No. NR011923, April 1967.

Adequacy of V/STOL wind-tunnel techniques is determined, and practical model-to-wind-tunnel-size guides are established. Theoretical wind-tunnel wall correction analyses are assessed; and V/STOL aircraft and large-scale models are investigated in the Ames 40-by-80-foot wind tunnel to determine performance, stability and control, cross flow effects on the lifting-propulsion system performance, and dynamics for correlation with flight test results.

Roberts, S.C., Stewart, A.W., Boaz, V.L., Bryant, G.D., and Mertaugh, L.J., XV-11A DESCRIPTION AND PRELIMINARY FLIGHT TEST, Mississippi State University, USAAVLABS Technical Report 67-21, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, May 1967, AD 654 469.

The XV-11A is a polyester-reinforced fiberglass STOL aircraft. This four-place aircraft, powered by a 250-horsepower T-63 turbine engine, was designed to achieve high lift coefficients by means of a variable-camber wing with distributed suction boundary layer control. A shrouded propeller was used for thrust augmentation at low forward velocities, and beta control on the propeller was successfully used as a drag increment for glide path control. To date, the XV-11A aircraft has flown 49 flights with a total flight time of 35 hours. The majority of the flight time was involved in aerodynamic research of the shrouded propeller and of the distributed suction boundary layer control system, and in an evaluation of the general handling characteristics of the aircraft. A minimum of performance data was collected since the primary objective was aerodynamic research. The fiberglass material demonstrated the excellent possibilities of this type of construction when complex, aerodynamically smooth curvatures are desired.

Feistel, T.W., and Imis, R.C., RESULTS OF A BRIEF FLIGHT INVESTIGATION OF A COIN-TYPE STOL AIRCRAFT, NASA TN D-4141, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, August 1967.

The aircraft tested to gain experience with a COIN (for COunter INsurgency) type STOL aircraft had two propellers driven by turbine engines, and double-hinged, single-slotted flaps to deflect the slipstream on the largely immersed wing. It was capable of good low-speed performance and had acceptable handling qualities in the STOL regime (with landing and takeoff distances consistently less than 800 feet over a 50-foot obstacle), provided the possibility of engine failure was ignored. This performance was achieved, despite flaps with only medium effectiveness, because the aircraft had a low aspect ratio, a high power loading, and a no-flare landing gear design. It is shown that the performance of the test aircraft as flown (ignoring engine failure) compared favorably with that of a large four-engine STOL aircraft, tested previously, which was much more sophisticated (it included a fail-safe propulsion system). If flown above the minimum single-engine control speed, in compliance with the normal safety restrictions for twin-engine airplanes, major aspects of the performance of the test aircraft are no better than that obtainable with many small twins in current production, and most of the original objectives of the COIN concept are compromised.

Innis, R.C., Holzhauser, C.A., and Gallant, R.P., FLIGHT TESTS UNDER IFR WITH AN STOL TRANSPORT AIRCRAFT, NASA TN D-4939, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, 1968.

An STOL transport was studied in instrument flight. This aircraft was flown on 7-1/2° and 2-1/2° ILS approaches. It could be flown comfortably and accurately on the 7-1/2° ILS at 60 knots to 200 feet above the runway. The descent and deceleration capabilities were more than adequate in the approach and landing configuration, but they were not sufficient in the preapproach configuration. The handling characteristics during the instrument flight were generally satisfactory, except for moderate heading excursions at low speeds and moderate angle-of-attack excursions at the rear center of gravity. These characteristics, while not satisfactory, were acceptable and are considered to be general problems of STOL aircraft operations.

Cook, A.M., Innis, R.C., and Rolls, L.S., FLIGHT-DETERMINED AERODYNAMIC PROPERTIES OF A JET-AUGMENTED, AUXILIARY-FLAP DIRECT-LIFT CONTROL SYSTEM INCLUDING CORRELATION WITH WIND TUNNEL RESULTS, TN D-5128, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, May 1969.

Alvarez-Calderon, A., INVERTING FLAP FLIGHT TEST, Fabrica Nacional De Aeroplanos S.A.; Defense Documentation Center Summary, Air Force Dynamics Laboratory, Wright-Patterson AFB, Ohio, August, 1968.

The applicability and operational suitability of the inverted wing flap as a high lift device for improved aircraft performance, specifically the STOL characteristics, are demonstrated.

## **2. AERODYNAMIC STUDIES OF HIGH-LIFT DEVICES**

### **2.1 PASSIVE DEVICES (NO SLIPSTREAM EFFECTS)**

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Bamber, M.J., WIND-TUNNEL TESTS ON AN AIRFOIL EQUIPPED WITH A SPLIT FLAP AND A SLOT, NACA TN 324, National Advisory Committee for Aeronautics, Washington, D.C., 1929.

Wenzinger, C.J., and Loeser, O., Jr., WIND TUNNEL PRESSURE DISTRIBUTION TESTS ON AN AIRFOIL WITH TRAILING EDGE FLAP, NACA TN 326, National Advisory Committee for Aeronautics, Washington, D.C., 1929.

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Wenzinger, C.J., WIND-TUNNEL INVESTIGATION OF ORDINARY AND SPLIT FLAPS ON AIRFOILS OF DIFFERENT PROFILE, NACA TR 554, National Advisory Committee for Aeronautics, Washington, D.C., 1936.

Platt, R.C., and Abbott, I.H., AERODYNAMIC CHARACTERISTICS OF NACA 23012 AND 23021 AIRFOILS WITH 20-PERCENT-CHORD EXTERNAL-AIRFOIL FLAPS OF NACA 23012 SECTION, NACA TR 573, National Advisory Committee for Aeronautics, Washington, D.C., 1936.

Wenzinger, C.J., WIND-TUNNEL INVESTIGATION OF TAPERED WINGS WITH ORDINARY AILERONS AND PARTIAL-SPAN SPLIT FLAPS, NACA TR 611, National Advisory Committee for Aeronautics, Washington, D.C., 1937.

Wenzinger, C.J., PRESSURE DISTRIBUTION OVER A CLARK Y-H AIRFOIL SECTION WITH A SPLIT FLAP, NACA TN 627, National Advisory Committee for Aeronautics, Washington, D.C., 1937.

Wenzinger, C.J., PRESSURE DISTRIBUTION OVER AN NACA 23012 AIRFOIL WITH AN NACA 23012 EXTERNAL-AIRFOIL FLAP, NACA TR 614, National Advisory Committee for Aeronautics, Washington, D.C., 1938.

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Wenzinger, C.J., and Harris, T.A., WIND-TUNNEL INVESTIGATION OF AN NACA 23012 AIRFOIL WITH VARIOUS ARRANGEMENTS OF SLOTTED FLAPS, NACA TR 664, National Advisory Committee for Aeronautics, Washington, D.C., 1939.

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## 2.1 TILT WING

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The aerodynamics of tilt-wing V/STOL aircraft, specifically the effects of wing span and wing stall, are discussed. It is found that a large wing span is desirable



from the transition, STOL, and cruise performance standpoints. The wing tends to stall in transition, particularly in descent, and has serious effects on performance, flying qualities, and buffet. The wing stalling and its adverse effects can be relieved or eliminated by the use of sufficiently large wing chord, flap, and leading-edge high-lift devices. Ground proximity tends to cause an increase in lift, but it also causes adverse dynamic effects on flying qualities and adverse effects on STOL performance. Treated in detail are (1) slipstream flow along the ground; (2) hovering control power in roll, yaw, and pitch; and (3) unstable pitching and rolling oscillations in hovering flight.

Fay, C.B., A CURSORY ANALYSIS OF THE VTOL TILT-WING PERFORMANCE AND CONTROL PROBLEMS, New York Academy of Sciences, Annals, Vol. 107, Art. 1, March 1963, pp 102-146.

The various problems pertaining to the performance and control characteristics of the tilt-wing VTOL configuration are discussed. The analysis developed uncovers and illustrates some of the basic aerodynamic characteristics and their consequences. Wind-tunnel tests conducted on several models to determine the transition performance and control characteristics, as well as methods of testing powered models, are covered. The effects of wing span and chord on forward flight performance are analyzed. Also treated is the effectiveness of various types of control methods proposed for the tilt wing. Problems such as coupling and variation of control power with ground effect are included. Operational techniques and their effect on safety are discussed briefly.

Fink, M.P., Mitchell, R.G., and White, L.C., AERODYNAMIC DATA ON LARGE SEMISPAN TILT-WING WING WITH 0.6-DIAMETER CHORD, SINGLE SLOTTED FLAP, AND SINGLE PROPELLER ROTATING UP AT TIP, NASA TN D-1586, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, October 1964.

The wing had a chord-to-propeller-diameter ratio of 0.6, a single-slotted flap, an aspect ratio of 4.05 (2.025 for the semispan), a taper ratio of 1.0, and an NACA 4415 airfoil section. The basic leading-edge configuration had practically no stall on that portion of the wing immersed in the propeller slipstream at angles well above those corresponding to the peak of the lift curve for the high thrust conditions corresponding to operation in the STOL range of flight; in general, the stall on the wing center section coincides with the angle of attack for maximum lift for the low thrust coefficients.

Spreemann, K. P., INVESTIGATION OF A SEMISPAN TILTING-PROPELLER CONFIGURATION AND EFFECTS OF RATIO OF WING CHORD TO PROPELLER DIAMETER ON SEVERAL SMALL CHORD TILTING-WING CONFIGURATIONS AT TRANSITION SPEEDS, NASA TN D-1815, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1964.

An investigation of the effects of changes in the ratio of wing chord to propeller diameter of three tilting-wing and tilting-propeller VTOL models has been conducted in the 17-foot test section of the Langley 300-mph 7- by 10-foot tunnel. The models have wing-chord-propeller-diameter ratios of 0.333, 0.208, and 0.125, with a single propeller 2 feet in diameter located at the wing tips. The investigation indicated that reductions in the ratio of wing chord to propeller diameter made small changes in lift, drag, and pitching moment; this indicates that, with the small ratios of wing chord to propeller diameter in this investigation, these configurations would realize small aerodynamic forces and moments in comparison with those realized from direct propeller thrust. The data are used in an analysis in which a full-scale aircraft is assumed to be in steady, level flight.

Deckert, W. H., Page, V. R., and Dickinson, S. D., LARGE-SCALE WIND-TUNNEL TESTS OF DESCENT PERFORMANCE OF AN AIRPLANE MODEL WITH A TILT WING AND DIFFERENTIAL PROPELLER THRUST, NASA TN D-1857, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, 1964.

Tests were conducted to determine the wing stall, performance, and longitudinal stability and control characteristics of a large model of a V/STOL tilt-wing transport aircraft. The scope of the tests was limited primarily to the low-speed transitional regime. Test configurations included wing-tilt angles from  $0^\circ$  to  $40^\circ$ , double-slotted trailing-edge flaps deflected from  $0^\circ$  to  $60^\circ$ , various wing leading-edge devices, such as partial-span and full-span Kruger flaps and slats, and several ramps that extended from the top of the fuselage to the tilted-wing center section.

Mitchell, R. G., FULL-SCALE WIND-TUNNEL TEST OF THE VZ-2 VTOL AIRPLANE WITH PARTICULAR REFERENCE TO THE WING STALL PHENOMENA, NASA TN D-2013, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, December 1963.

A correlation was made at the trim level-flight condition, which showed good agreement between the wind-tunnel source data and corresponding flight data on lift and drag. The wind-tunnel force-test results, however, showed no apparent correlating factor with the flying-qualities problems associated with wing stall. Tuft tests did correlate with the acceptable or unsatisfactory flying characteristics

for certain flight conditions. There were flight conditions, however, for which the flying characteristics associated with extensive stalling could not be explained by the tuft data.

Winston, M. M., and Huston, R. J., WING PRESSURE MEASUREMENTS WITHIN THE PROPELLER SLIPSTREAM FOR A LARGE SCALE V/STOL WIND-TUNNEL MODEL SIMULATING TRANSITION, NASA TN D-2014, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, October 1963.

Wing-pressure data on tilt-wing, tilt-wing-with-slat, and deflected-slipstream configurations, obtained during tests of the model in the Langley full-scale tunnel, are presented for an angle-of-attack range corresponding to transition flight of a vertical or short takeoff and landing (V/STOL) aircraft. Included are pressure data for a range of flap deflections and lift-drag conditions corresponding to longitudinal acceleration and deceleration. A limited analysis of the pressure measurements for the tilt-wing configuration is also included.

Weiberg, J. A., and Giulianetti, D. J., LARGE-SCALE WIND-TUNNEL TESTS OF AN AIRPLANE MODEL WITH AN UNSWEPT TILT WING OF ASPECT RATIO 5.5, AND WITH VARIOUS STALL CONTROL DEVICES, NASA TN D-2133, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, 1964.

Tests were conducted to determine the effects of slats, flaps, wing-fuselage ramp fairing, and propeller rotation on the flow separation, buffet, and descent characteristics of a tilt-wing deflected-slipstream VTOL model. The results indicated that wing stall and resulting buffet in descending flight could be delayed approximately 15 knots by a slat, BLC nose flap, or increased trailing-edge flap effectiveness.

Fink, M. P., Mitchell, R. G., and White, L. C., AERODYNAMIC DATA ON A LARGE SEMISPAN TILTING WING WITH 0.6-DIAMETER CHORD, FOWLER FLAP, AND SINGLE PROPELLER ROTATING UP AT TIP, NASA TN D-2180, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, February 1964.

The wing had a chord of 0.6 propeller diameter, a Fowler flap, an aspect ratio of 4.05 (2.025 for the semispan), a taper ratio of 1.0, and an NACA 4415 airfoil section. Tuft tests showed no stall on the part of the wing immersed in the propeller slipstream at angles of attack well above that corresponding to the peak of the lift curve for the high-thrust conditions that occur in the STOL range of flight.

The wing-flap combination was found to be sufficiently effective to prevent wing stall except in the unprotected center section (judged from tuft-test results) over the entire range of STOL operating conditions covered in the tests, which included the conditions required for descent angles as high as about 20° for each test. The use of leading-edge high-lift or stall-control devices was not found to be beneficial in the conditions corresponding to the STOL flight range, because the wing did not stall without such devices.

Kirby, R.H., Schade, R.O., and Tosti, L.P., FORCE-TEST INVESTIGATION OF A 1/4-SCALE MODEL OF THE MODIFIED VZ-2 AIRCRAFT, NASA TN D-2382, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, August 1964.

A force-test investigation was conducted to determine the longitudinal aerodynamic characteristics and the aileron control effectiveness of a 1/4-scale model of the modified VZ-2 tilt-wing VTOL aircraft equipped with a full-span slotted flap. The model was also tested over the transition range with a leading-edge droop modification. The results of the force tests indicated that the use of full-span slotted flaps produced sizable increases in lift that resulted in considerable reductions in the wing incidence angles required throughout the transition range; these reductions in wing incidence were very beneficial in reducing wing stalling in the transition range. The use of leading-edge droop had no appreciable effect on the static longitudinal characteristics. The use of full-span ailerons as a yaw control for hovering and low-speed transition flight appears to offer considerable promise; however, the phasing-in of some roll-producing control is necessary fairly early in the transition to eliminate the adverse roll that is encountered.

Schade, R.O., and Kirby, R.H., EFFECT OF WING STALLING IN TRANSITION ON A 1/4-SCALE MODEL OF THE VZ-2 AIRCRAFT, NASA TN D-2383, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1964.

An experimental flight investigation was conducted to determine the dynamic lateral stability and control characteristics of a remotely controlled 1/4-scale model of the VZ-2 tilt-wing VTOL aircraft. The model was equipped with a full-span slotted flap and a Krueger-type nose flap. The investigation included both level-flight and descent conditions over the transition range where wing stalling occurred. Flight tests of the model in the flaps-retracted configuration indicated that the model had poor lateral flight characteristics in level flight and that these characteristics generally consisted of wing dropping and erratic large-amplitude yawing motions normally associated with wing stall. The full-span slotted flap and the Krueger-type nose flap when used in combination resulted in large improvements in lateral

flight characteristics in both level and descent flights. When the two types of flaps were used separately, the lateral flight characteristics did not improve as much as when the flaps were used in combination. The full-span slotted flap produced the greatest improvement in lateral flight characteristics. Use of the full-span slotted flap, however, caused a considerable reduction in longitudinal flight characteristics. When the mode of propeller rotation was such that the blades were going upward at wing tips, the wing-dropping tendency was worse, but the yawing characteristics were better than when the blades were going downward at the wing tips.

Fink, M.P., Mitchell, R.G., and White, L.C., AERODYNAMIC DATA ON LARGE SEMISPAN TILTING WING WITH 0.6-DIAMETER CHORD, SINGLE-SLOTTED FLAP, AND SINGLE PROPELLER ROTATING DOWN AT TIP, NASA TN D-2412, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, August 1964.

An investigation was made in a full-scale tunnel to determine the longitudinal aerodynamic characteristics of a large-scale semispan V/STOL tilt-wing configuration having a single propeller with propeller rotation such that the blades rotated downward at the wing tip and upward near the root. The wing had a chord-to-propeller-diameter ratio of 0.6, a single-slotted flap, an aspect ratio of 4.05 (2.025 for the semispan), a taper ratio of 1.0, and an NACA 4415 airfoil section. The data were examined to observe general trends only; they were not analyzed in detail. The portion of the wing outboard of the nacelle rarely stalls, evidently because of the wing-tip effect and because of the reduction in angle of attack over that portion of the wing caused by the slipstream rotation that is downward at the wing tip. The stall starts at the trailing edge of the wing root and progresses smoothly forward and outboard. The use of the leading-edge slat is beneficial in that it extends the lift curves to higher angles of attack and higher maximum lift coefficients, and it was also beneficial with flap up at low values of thrust coefficient.

Anon., ADDITIONAL TEST OF A 1/4.5-SCALE POWERED SEMISPAN MODEL OF THE CANADAIIR, LTD., CL-84 AIRPLANE, CVAL 402, Canada Limited, Subsidiary of General Dynamics Corporation, Montreal, Canada, 1965.

Thomas, R.O., WIND-TUNNEL INVESTIGATION OF A 1/20-SCALE POWERED MODEL TILT-WING V/STOL SEAPLANE IN THE CRUISE CONFIGURATION, Report DTMB-2079, David Taylor Model Basin, Washington, D.C., August 1965, AD 472 709.

Low-speed wind tunnel tests were conducted on a 1/20-scale powered model of a proposed open-ocean V/STOL seaplane. Some cruise flight performance parameters and the effects of power on longitudinal and lateral stability and control, in the cruise flight regime, were determined.

Longhurst, W.S., REPORT ON STABILITY AND CONTROL TESTING OF TILT-WING V/STOL AIRCRAFT, SAE 660315, April 1966.

Fink, M.P., Mitchell, R.G., and White, L.D., AERODYNAMIC DATA ON A LARGE SEMISPAN TILTING WING WITH A 0.5 DIAMETER CHORD, DOUBLE-SLOTTED FLAP, AND BOTH LEFT- AND RIGHT-HAND ROTATION OF A SINGLE PROPELLER, NASA TN D-3375, National Aeronautics and Space Administration, Washington, D.C., April 1966.

An investigation has been made in the Langley full-scale tunnel to determine the longitudinal aerodynamic characteristics of a large-scale semispan V/STOL tilt-wing configuration having a single propeller which was tested for both right- and left-hand rotation. The wing had a chord-to-propeller-diameter ratio of 0.5, a double-slotted flap, an aspect ratio of 4.88 (2.44 for the semispan), a taper ratio of 1.0, and an NACA 4415 airfoil section. The data have not been analyzed in detail but have been examined to observe the predominant trends. It was found that the direction of propeller rotation had no significant effect on the lift or descent capability attainable, although different types of flow-control devices were required to achieve the same results with different directions of rotation. The descent capability was determined from the values of attainable drag-to-lift ratios without stalling of any part of the wing within the propeller slipstream. The use of flaps was very effective in increasing the descent capability for either mode of rotation. For example, with the most favorable combination of flow-control devices tested, virtually no descent capability prior to wing stalling was achieved with 0° flap deflection; whereas with 40°, 60°, or 70° flap deflection, a descent capability of about 20° was achieved.

Fink, M.P., AERODYNAMIC DATA ON A LARGE SEMISPAN TILTING WING WITH A 0.5-DIAMETER CHORD, A DOUBLE-SLOTTED FLAP, AND LEFT-HAND AND RIGHT-HAND ROTATION OF A SINGLE PROPELLER, IN PRESENCE OF FUSELAGE, NASA TN D-3674, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1966.

Anon., TESTS OF A 1/4.5-SCALE REFLECTION PLANE POWERED MODEL OF THE CANADAIR, LTD., CL-84 AIRPLANE WITH AN EXTENDABLE CHORD WING, Canadair Limited, Subsidiary of General Dynamics Corporation, Montreal, Canada, 1967.

Fink, M.P., and Mitchell, R.G., AERODYNAMIC DATA ON A LARGE SEMISPAN TILTING WING WITH A 0.5-DIAMETER CHORD, A SINGLE SLOTTED FLAP AND BOTH LEFT-HAND AND RIGHT-HAND ROTATION OF A SINGLE PROPELLER, NASA TN D-3754, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1967.

McKinney, M.O., AERODYNAMICS AND STABILITY AND CONTROL OF TILT-WING V/STOL AIRCRAFT, Langley Research Center, Langley Station, Virginia, Defense Documentation Center Summary, Acc. No. NR000490, March 1967.

Basic research information applicable to tilt-wing propeller-driven V/STOL aircraft in the areas of aerodynamics and stability and control including dynamic stability is given.

Fink, M.P., AERODYNAMIC DATA ON LARGE SEMISPAN TILTING WING WITH 0.5-DIAMETER CHORD, SINGLE-SLOTTED FLAP, AND SINGLE PROPELLER 0.19 CHORD BELOW WING, NASA TN D-3884, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, April 1967.

An investigation has been made in the Langley full-scale (30- by 60-foot) tunnel to determine the longitudinal aerodynamic characteristics of a large-scale semispan V/STOL tilt-wing configuration with a single propeller which was tested for both modes of rotation. The model had a half-fuselage on which loads were measured separately. The wing had a chord-to-propeller-diameter ratio of 0.5, a 40-percent-chord single-slotted flap, an aspect ratio of 4.88 (2.44 for the semispan), a taper ratio of 1.0, and an NACA 4415 airfoil section. The data have not been analyzed in detail but have been examined to observe the predominant trends. It was found that the direction of propeller rotation had a very significant effect on the lift and descent capability (as determined from drag-lift ratios attainable without stalling of any part of the wing within the propeller slipstream) and that up-at-the-tip rotation gave the more favorable results. The use of a trailing-edge flap was also very effective in increasing the descent capability. The use of leading-edge flow-control devices was very effective in increasing the descent capability and lift for the case of down-at-the tip propeller rotation where the characteristics without such devices were poor, but was much less effective for the case of up-at-the tip propeller rotation where reasonably favorable results were achieved without leading-edge devices. For the most favorable combination of the configuration variables, descent angles of nearly  $29^\circ$  were achieved over the entire test range of power conditions.

Curnutt, R.A., and Curtiss, H.C., COMPARISON OF LONGITUDINAL STABILITY CHARACTERISTICS OF THREE TILT-WING VTOL AIRCRAFT DESIGNS, Princeton University, USAAVLABS Technical Report 66-64, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, January 1968, AD 667 983.

Traybar, J.J., AERODYNAMIC CHARACTERISTICS OF A GENERAL TILT-WING/PROPELLER MODEL TESTED AT SLOW SPEEDS AND HIGH ANGLES OF ATTACK, Princeton University, USAAVLABS Technical Report 67-79, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, February 1968, AD 671 666.



The aerodynamic characteristics of a general tilt-wing/propeller model were investigated at the Princeton Dynamic Model Track Facility. Experiments included test conditions corresponding to free-stream velocities from slow backward flight through hovering and transition. Wing incidence angles ranging from 30 degrees (forward flight) to 90 degrees (hovering flight) were investigated. The experimental data are presented in graphs of lift, horizontal force, and pitching moment versus thrust in coefficient form based on free-stream velocity.

Dickinson, S. O., Page, V. R., and Deckert, W. H., LARGE SCALE WIND-TUNNEL INVESTIGATION OF AN AIRPLANE MODEL WITH A TILT WING OF ASPECT RATIO 8.4 AND FOUR PROPELLERS, IN THE PRESENCE OF A GROUND PLANE, NASA TN D-4493, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, April 1968.

Aerodynamic characteristics of a large-scale model of a tilt-wing V/STOL transport aircraft are presented. The investigation was conducted in the Ames 40-by 80-foot wind tunnel at various heights above a fixed ground plane. Free-stream Reynolds number varied from 0 to 2.9 million. Model configuration included wing tilt angles from 0° to 90°, trailing-edge flap deflections from 0° to 60°, and partial-span wing leading-edge slats. Results show that ground proximity decreased lift up to 20 percent (depending on wing tilt angle), decreased drag, and increased nose-down pitching moment.

Boyden, R. P., and Curtiss, H. C., INVESTIGATION OF THE LATERAL/DIRECTIONAL STABILITY CHARACTERISTICS OF A FOUR-PROPELLER TILT-WING VTOL MODEL, Princeton University, USAAVLABS Technical Report 68-19, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, April 1968, AD 673 147.

Results of an experimental investigation to determine the lateral/directional stability characteristics of a four-propeller tilt-wing VTOL aircraft using a one-tenth scale dynamically similar model are presented. Test conditions include wing incidences of 89, 70 and 30 deg. Measurements of the transient motion of the model in the lateral/directional degrees of freedom and the static lateral/directional stability derivatives were made. The transient and steady-state data are analyzed assuming that the motions of the vehicle may be described by linearized equations, and the resulting static and dynamic derivatives are presented. The characteristics of the lateral/directional dynamic motion of the full-scale vehicle as predicted by the tests of the dynamically similar model are determined and discussed. All data are presented for a center-of-gravity position of 9-percent MAC, which is ahead of the most forward C.G. position of the aircraft (15-percent MAC), and the horizontal tail and flap programs differ from those presently used on the aircraft.



## 2.4 TILT AND DUCTED PROPELLER

Koenig, D.G., Greif, R.K., and Kelly, M.W., FULL-SCALE WIND TUNNEL INVESTIGATION OF THE LONGITUDINAL CHARACTERISTICS OF A TILTING-ROTOR CONVERTIPLANE, NASA TN D-35, National Aeronautics and Space Administration, Washington, D.C., 1959.

Kuhn, R.E., and Hayes, W.C., WIND-TUNNEL INVESTIGATION OF LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF THREE PROPELLER-DRIVEN VTOL CONFIGURATIONS IN THE TRANSITION SPEED RANGE, INCLUDING THE EFFECTS OF GROUND PROXIMITY, NASA TN D-55, National Aeronautics and Space Administration, Washington, D.C., 1960.

Yaggy, P.F., and Mort, K.W., A WIND-TUNNEL INVESTIGATION OF A 4-FOOT-DIAMETER DUCTED FAN MOUNTED ON THE TIP OF A SEMISPAN WING, NASA TN D-776, National Aeronautics and Space Administration, Washington, D.C., March 1961.

Grumfield, K.J., AERODYNAMIC CHARACTERISTICS OF A FOUR-PROPELLER TILT-WING VTOL MODEL WITH TWIN VERTICAL TAILS, INCLUDING EFFECTS OF GROUND PROXIMITY, NASA TN D-901, National Aeronautics and Space Administration, Washington, D.C., June 1961.

A wind-tunnel investigation was made of the aerodynamic stability, control, and performance characteristics of a four-propeller tilt-wing VTOL airplane model employing flaps and speed brakes through the transition speed range. The wing was stalled for steady, level flight for all conditions of the investigation; however, the flapped configuration did produce a higher maximum lift. The wing stall resulted in an appreciable reduction of aileron effectiveness during the transition. Out of ground effect, the low horizontal tail did not appear to be in an adverse flow field as had been expected, and it showed no erratic changes in effectiveness; however, in ground effect, a large nose-down moment was experienced by the model. It is concluded that the configuration is directionally stable and possesses positive dihedral effect throughout the transition, and the data show no signs of erratic flow at the vertical tails.

Payne, H.E., III, APPLICATION OF SMALL-SCALE PROPELLER TEST DATA TO V/STOL AIRCRAFT DESIGN, Princeton Report 503, Princeton University, Princeton, New Jersey, 1961.

Davenport, E. E., and Spreeman, K. P., TRANSITION CHARACTERISTICS OF A VTOL AIRCRAFT POWERED BY FOUR DUCTED TANDEM PROPELLERS, NASA TN D-2254, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, April 1964.

Results are presented of a wind-tunnel investigation of the aerodynamic stability and control characteristics of a vertical takeoff and landing (VTOL) aircraft configuration powered by four tilting ducted propellers arranged in tandem pairs. The two front ducted propellers were mounted close inboard and near the top of the fuselage on the same level as the rear ducted propellers, which were mounted outboard on the tips of a short wing. The results indicate that the nose-up moment encountered in transition arises from two sources: the nose-up moment of the ducts themselves and the downwash at the rear element (pair of ducts and wing) that reduces the percentage of the lift produced by the rear element.

Hesby, A., and Sherman, E. W., MODEL X-22A WIND TUNNEL TEST DATA REPORT FOR THE FULL SCALE POWERED DUCT MODEL, Report 2127-921007, Bell Aerosystems Co., Buffalo, New York, August 1965, AD 487 970L.

A full-scale powered duct model for the X-22A VTOL aircraft was tested in the Ames 40- by 80-foot wind tunnel to obtain aerodynamic and propulsive data in the hovering, transition, and conventional flight regimes. This report presents data obtained during these tests. Forces and moments were measured on the complete unit and on the shroud separately. Shroud internal and external pressure distributions were recorded, and selected propeller blade stress measurements were made.

Spreemann, K. P., WIND TUNNEL INVESTIGATION OF LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A POWERED FOUR-DUCT-PROPELLER VTOL MODEL IN TRANSITION, NASA TN D-3192, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1966.

Bramwell, A. R. S., TRANSIENT AERODYNAMIC FORCES ON A TILT-PROPELLER VTOL AIRCRAFT IN HOVERING, London University, Department of Aeronautics, London, England, September 1967.

Techniques are described for calculating the transient pressures and forces on surfaces near lifting rotor blades in VTOL configurations. The investigation shows that the interference forces can be very large when the rotor is close to the wing and the wing chord is large. For a rotor of given thrust, the transient loads are found to be inversely proportional to the number of blades. The mean value of these forces is small, however, and not likely to seriously affect the aircraft performance, being generally smaller than the downwash drag effect.

Spreemann, K.P., WIND TUNNEL INVESTIGATION OF LATERAL AERODYNAMIC CHARACTERISTICS OF A POWERED FOUR-DUCT PROPELLER VTOL MODEL IN TRANSITION, NASA TN D-4343, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1968.

An investigation to determine the lateral and directional aerodynamic characteristics of a powered four-duct-propeller 1/5-scale model of a VTOL airplane was conducted in the 17-foot test section of the Langley 300-mph 7-by 10-foot tunnel. The model was tested through a sideslip-angle range at angles of attack of 0°, 8°, and 12° and with duct deflection angles from -5° to 90° at various thrust coefficients from hovering to conventional forward flight. The initial cruise configuration had natural directional stability in the power-off/low-angle-of-attack conditions (0° and 8°) and became stable at the high angle-of-attack condition (12°). A larger vertical tail having a higher aspect ratio than was used on the initial configuration provided a slightly stable model in the power-off condition; however, in the power-on condition, the model became unstable in the lower transition-speed range regardless of tail geometry. Tail-wing fairings of various sizes and shapes significantly increased the directional stability. Directional deflection of the elevons (vanes) in the ducts provided large control increments in roll and yaw through the transition-speed range; however, the total requirements for trim and control will necessitate the use of both elevon deflection and differential propeller thrust throughout the transition-speed range.

Demetropoulos, J., X-19 PROPELLER TECHNOLOGY PROGRAM. Curtiss-Wright Corp., Curtiss Div., Air Force Flight Dynamics Laboratories, Wright-Patterson AFB, Ohio, Defense Documentation Center Summary Acc. No. DF476097, February, 1968.

The aerodynamic characteristics of the X-19 and CL-84 V/STOL propellers in the NASA-Ames 40-by 80-foot wind tunnel were evaluated, and the blade pressure distribution (air loads) data on the CL-84 propeller were obtained; these data will be used to improve the existing analytical methods for prediction of V/STOL prop/rotor performance and to increase the available knowledge of the fundamental effects of propeller rotation on the blade airfoil characteristics.

## **2.5 JET FLAPS**

**Maskell, E. G., and Gates, S. B., PRELIMINARY ANALYSIS FOR A JET FLAP SYSTEM IN TWO-DIMENSIONAL INVISCID FLOW, RAE AERO-2552, Royal Aircraft Establishment, Farnborough, England, June 1955.**

**Williams, J., and Alexander, A. J., THREE-DIMENSIONAL WIND-TUNNEL TESTS OF A 30 DEGREE JET-FLAP MODEL, PERF 1399, Aeronautical Research Council, Performance Committee, Great Britain, November 1955.**

**Lowry, J. G., and Vogler, R. D., WIND-TUNNEL INVESTIGATION AT LOW SPEEDS TO DETERMINE THE EFFECT OF ASPECT RATIO AND END PLATES ON A RECTANGULAR WING WITH JET FLAPS DEFLECTED 85 DEGREES, NACA TN 3863, National Advisory Committee for Aeronautics, Washington, D.C., 1956.**

**Lowry, J. G., Campbell, J. M. and Campbell, J. P., THE JET-AUGMENTED FLAP, Preprint No. 715, S.M.F. Fund Paper, Institute, Aero Sciences, January 1957.**

**Chaplin, H. R., WIND TUNNEL INVESTIGATION OF A SMALL SCALE TWO-DIMENSIONAL JET FLAP WING MODEL OVER A LARGE RANGE OF JET DEFLECTIONS, AERO Report 929, Navy, David W. Taylor Model Basin, Carderock, Maryland, October 1957.**

**Aoyagi, K., and Hickey, D. H., FULL-SCALE WIND TUNNEL INVESTIGATION OF A JET FLAP IN CONJUNCTION WITH A PLAIN FLAP WITH BLOWING BOUNDARY-LAYER CONTROL ON A 35 DEGREE SWEEP-BACK-WING AIRPLANE, NASA Memo 2-20-59A, National Aeronautics and Space Administration, Washington, D.C., 1959.**

**Korbacher, G. K., THE JET FLAP AND STOL, Part II, Decennial Symposium Proceeding, Toronto University, Institute of Aerophysics, Toronto, Canada, 1959.**

**Butler, S. F. J., and Williams, J., FURTHER COMMENTS ON HIGH-LIFT TESTING IN WIND TUNNELS WITH PARTICULAR REFERENCE TO JET BLOWING MODELS, AGARD Report 304, Advisory Group for Aeronautical Research and Development, Paris, France, March 1959.**

Yen, K. T., ON THE THRUST HYPOTHESIS FOR THE JET FLAP INCLUDING MIXING EFFECTS, TR AE 5902, Rensselaer Polytechnic Institute, Dept. of Aeronautical Engineering, June 1959.

Wood, M. N., FURTHER WIND-TUNNEL EXPERIMENTS ON A RECTANGULAR-WING JET-FLAP MODEL OF ASPECT RATIO 6, AERO-2651, Royal Aircraft Est., Farnborough, England, September 1959.

Spreemann, K. P., and Davenport, E. E., INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF A COMBINATION JET-FLAP AND DEFLECTED-SLIPSTREAM CONFIGURATION AT ZERO AND LOW FORWARD SPEEDS, NASA TN D-363, National Aeronautics and Space Administration, Washington, D. C., 1960.

Korbacher, G. D., and Sridhar, K., REVIEW OF THE JET FLAP, Toronto University, Institute of Aerophysics, Review 14, May 1960.

Fimple, W. R., AN EXPERIMENTAL INVESTIGATION OF THE AERODYNAMIC FORCES AND MOMENTS ON A JET-FLAPPED WING IN THE PRESENCE OF A PROPELLER SLIPSTREAM AND A FREE STREAM, Princeton University, Princeton, New Jersey, 1961.

Fink, M. P., AERODYNAMIC CHARACTERISTICS, TEMPERATURE, AND NOISE MEASUREMENTS OF A LARGE-SCALE EXTERNAL FLOW JET-AUGMENTED-FLAP MODEL WITH TURBOJET ENGINES OPERATING, NASA TN D-943, National Aeronautics and Space Administration, Washington, D. C., September 1961.

An investigation has been conducted in the Langley full-scale tunnel on a large-scale model powered by turbojet engines with flattened rectangular nozzles. The wing had a 35° sweep of the leading edge, and aspect ratio of 6.5, a taper ratio of 0.31, and NACA 65<sub>1</sub>-412 and 65-408 airfoils at the root and tip. The investigation included measurements of the longitudinal aerodynamic characteristics of the model with half-span and full-span flaps and measurements of the sound pressure and skin temperature on the portions of the lower surface of the wing immersed in the jet flow. The tests were conducted over a range of angles of attack from -8° to 16° for Reynolds numbers from  $1.8 \times 10^6$  to  $4.4 \times 10^6$  and a range of momentum coefficients from 0 to 2.0.

Foley, W. M., AN EXPERIMENTAL STUDY OF JET-FLAP THRUST RECOVERY, Report 136, Stanford University, July 1962.

**Tsongas, G.A., VERIFICATION AND EXPLANATION OF THE CONTROLLABILITY OF JET FLAP THRUST, SUDAER No. 138, Stanford University, California, October 1962.**

Since the practical use of "air" jet flaps for reducing the approach and landing speeds of airplanes depends largely upon whether the resulting forward jet-flap thrust can be suppressed, experiments were conducted to see if this type of thrust control was possible and if the mechanism of such control could be identified. Devices which were thought to have potential merit as jet thrust suppressors were investigated by determining the forces experienced by appropriately modified forms of a jet-flapped model wing under the conditions of two-dimensional flow. Results indicated that the extent of thrust control provided by large deflections of a simple jet flap was not augmented by any of the auxiliary devices tested. However, force tests showed that jet-flap thrust recovery in two-dimensional flow can be controlled and practically nullified, without sacrifice of lift, by the use of large flap deflections ( $95^\circ$ ). Flow visualization studies showed that the aerodynamic phenomenon which enables such control is the development, with large flap deflections, of a rapidly diverging, low-energy wake which lies immediately behind and above the deflected jet and is almost free of a large-scale turbulence.

**Quanbeck, A.H., FURTHER VERIFICATION OF JET FLAP THRUST RECOVERY AND IDENTIFICATION OF ITS MECHANISM, SUDAER 144, Stanford University, Stanford, California, 1963.**

An experimental investigation was conducted to extend and clarify the initial verification of Stratford's jet flap thrust-recovery theorem and to identify the mechanism of thrust recovery. Models were tested in a two-dimensional airstream characterized by free upper- and lower-surface boundaries. The tests consisted of a simultaneous determination of the forces and distributions of external pressure which resulted from the systematic variation of flap deflection and jet blowing rate. Analysis of force test data demonstrated that the variation of jet efflux direction had little or no effect upon thrust recovery so long as flow detachment did not occur. Verification of the thrust-recovery theorem was thereby extended to include jet-flapped wings characterized by oblique and streamwise jet efflux.

**Alexander, A.J., EXPERIMENTS ON A JET-FLAP DELTA WING IN GROUND EFFECT, College of Aeronautics, Cranfield, England, 1963.**

**Eyre, R.C.W., DESCRIPTION OF MODEL AND TEST RIG FOR FLAP BLOWING TESTS WITH SLIPSTREAM IN THE 24 FOOT WIND TUNNEL, Royal Aircraft Establishment, London Min. of Aviation, Farnborough, England, October 1963.**

Korbacher, G.K., PERFORMANCE AND OPERATION OF QUASI TWO DIMENSIONAL JET FLAPS, Report 90, Toronto University Institute for Aerospace Studies, Toronto, Canada, 1963, AD 426 783.

True two-dimensional and quasi two-dimensional jet-flap test results are evaluated for experimental evidence in favor of or against the once much-disputed jet-flap thrust hypothesis. The thrust hypothesis is verified experimentally as conclusively as it has been proven theoretically. The development is presented of jet-flap characteristics for truly and quasi two-dimensional jet-flapped wings. For any desired lift, it renders any number of combinations of rate of blowing, jet-deflection angle, and angle of attack which can produce this lift. Also, it permits that amount of jet-sheet thrust which can be recovered as propulsive thrust or which is nullified by the drag of the jet-flapped wing to be read off simultaneously. The ratio of these values reflects on the performance and economy of operation of this wing. If, then, the production of a specific lift is optimized with respect to the lowest expenditure in blowing at the smallest possible drag, an "operating line" can be defined and added to the jet-flap characteristics. The range of economical jet-flap operation was found to coincide with the region in which any change in the rate of blowing results in exactly the same change in the measured thrust.

Alexander, A.J., and Williams, J., WIND-TUNNEL EXPERIMENTS OF A RECTANGULAR-WING JET-FLAP MODEL OF ASPECT-RATIO 6., Aeronautical Research Council, London, England, 1964.

Butler, S. F. J., and Williams, J., FURTHER DEVELOPMENTS IN LOW-SPEED WIND TUNNEL TECHNIQUES FOR V/STOL AND HIGH LIFT MODEL TESTING, RAE TN AERO 2944, Aeronautical Research Council, Great Britain, London, January 1964.

Experimental methods of wind-tunnel testing of high-lift models with boundary-layer control and circulation control were previously described by the authors. Some of the advances since then, particularly those to expedite investigations on jet and fan lift models at RAE, are discussed. Attention is concentrated on the following topics; (1) special mechanical and strain-gauge balance rigs for jet-blowing models; (2) engine exit and intake flow simulation at model scale; and (3) ground simulation by a moving-belt rig. The need, development, and application of these techniques are considered, together with some problems still to be overcome.

Garland, D.B. , JET-FLAP THRUST RECOVERY - ITS HISTORY AND EXPERIMENTAL REALIZATION, Paper 64-797, American Institute of Aeronautics and Astronautics, and Canadian Aeronautics and Space Institute, Joint Meeting, Ottawa, Canada, October 1964.

This paper reviews some aspects of the thrust-recovery hypothesis and illustrates the experimental results recently obtained with a detailed analysis of data from a jet-augmented flap wing, a configuration tested to provide a comparison with the augmentor wing. Some possible reasons for less than complete thrust recovery are presented. These include (1) measurement of recovered thrust at zero forward speed, which is sometimes less than the ideal or isentropic value; (2) increase in profile drag, due to separation of the flow around the airfoil; (3) "jet-mixing drag"; and (4) the presence of a large diffuse wake of low-energy, nonturbulent air immediately above the jet. The implications of thrust recovery to STOL performance are considered with respect to takeoff, landing, and approach.

Lissaman, P.B.S. , AERODYNAMIC CHARACTERISTICS OF JET-FLAPPED AIRFOILS IN GROUND EFFECT, Vehicle Research Corp., Pasadena, California, December 1964.

Wynanski, I. , THE EFFECT OF JET ENTRAINMENT ON LOSS OF THRUST FOR A TWO-DIMENSIONAL SYMMETRICAL JET-FLAP AEROFOIL, Aeronautical Quarterly, Vol. 17, February 1966, pp 31-52.

Butler, S.F.J. , Guyett, M.B. , and Moy, D.A. SIX-COMPONENT LOW-SPEED TUNNEL TESTS OF JET-FLAP COMPLETE MODELS WITH VARIATION OF ASPECT RATIO, DIHEDRAL, AND SWEEPBACK, INCLUDING THE INFLUENCE OF GROUND PROXIMITY, RAE AERO 2652, Aeronautical Research Council, London, England, 1967.

Turner, T.R. , A MOVING-BELT GROUND PLANE FOR WIND-TUNNEL GROUND SIMULATION AND RESULTS FOR TWO JET-FLAP CONFIGURATIONS, NASA Document, Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio, November 1967.

Corsiglia, V.R. , Koenig, D.G. , and Morelli, J.P. , AERODYNAMIC CHARACTERISTICS OF A LARGE-SCALE MODEL WITH UNSWEPT WING AND AUGMENTED JET FLAP, TN D-4610, Ames Research Center Report, National Aeronautics and Space Administration, Moffett Field, California, June 1968.



Williams, J.G.M., and Hansen, S.G., RESEARCH ON A JET FLAP AIR-SEA CRAFT, DESCRIPTIVE NOTE: FINAL REPORT., LR 21445, Lockheed-California Company, June 1968, AD 835 352L.

This report describes the pre-test analysis and the results of two wind-tunnel investigations of a canard-configured, swept-wing model with jet-flap systems incorporated in both the wing and the canard. For a jet-flap airplane operating at trimmed lift coefficients of about  $C_L = 5$ , analysis indicates that the total blowing thrust demand for a canard-configured airplane is significantly less than that for a conventional aft-tail configuration. The canard-configured model appears to have satisfactory cruise characteristics, and there is little change in the static longitudinal stability on conversion to the STOL, jet-flap blowing mode. Out-of-ground-effect STOL characteristics are satisfactory at the low incidence proposed for operation; at a certain higher critical incidence, the wing stalls and a pitch-up condition ensues. Ground proximity has little effect upon the operational values of lift, static margin, trim, etc., but it does seriously erode the margin between the operating and critical incidence. Possible operational techniques with this airplane configuration provide it with powerful and rapid response characteristics in lift and pitch control.

Cooke, G.C., JET FLAPPED AIRFOILS IN GROUND PROXIMITY, TR-AE-6804, Rensselaer Polytechnic Inst., Troy, New York, January 1968.

The paper concerns the subsonic lift characteristics of airfoils in ground proximity with and without trailing-edge jet flaps. The study is restricted to the super-critical flow problem in which the jet flap does not impinge upon the ground. A linearized potential flow model in the form of integro-differential equations is constructed to analyze this physical problem. Solutions for the airfoil vortex intensity and jet-flap shape are found by representing these functions in a continuous manner by trigonometric series with unknown coefficients. The resulting algebraic equations are then solved by a pivotal points procedure. An alternate method for determining the lift characteristics of airfoils in ground proximity without jet flaps is also presented.

McCormick, B.W., INVESTIGATION OF THE TRAILING VORTEX SYSTEM FROM A JET FLAPPED WING, The Pennsylvania State University, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, Defense Documentation Center Summary, Acc.No. DF476333, February 1969.

An experimental investigation of the structure of the trailing vortex system generated by a wing operating at high-lift coefficient is described; the results are correlated with previously developed prediction methods. The results of this work will aid in

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## 2.6 BOUNDARY LAYER CONTROL

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Williams, J., and Butler, S. F., AERODYNAMIC ASPECTS OF BOUNDARY LAYER CONTROL FOR HIGH LIFT AT LOW SPEEDS, Advisory Group for Aeronautical Research and Development, Paris, France, January 1963, AD 426 377.

Streit, G., and Thomas, F., EXPERIMENTAL AND THEORETICAL INVESTIGATION ON BLOWN WINGS AND THEIR APPLICATION IN AIRCRAFT DESIGN (EXPERIMENTELLE UND THEORETISCHE UNTERSUCHUNGEN AN AUSBLASEFLUGELN UND IHRE ANWENDUNG BEIM FLUGZEUGENTWURF), IN: Wissenschaftliche Gesellschaft für Luft- und Raumfahrt e. V. (WGLR), Jahrestagung in Braunschweig Vom. 9. -12. 10. 62, Jahrbuch, 1963, pp 119-132.

Wind-tunnel investigation of the effect of the flap chord and the flap-nose radius on the aerodynamic coefficients of a wing profile with boundary-layer control through blowing over the flap length is described. The value of the momentum coefficient of blowing required to prevent flow separation is determined. The results obtained experimentally are compared with theory and with available experimental data. Calculations showing the effect of the lift increase obtained by blowing on the take-off and landing distances of an aircraft are presented.

Neal, B., THE STATIC AND FORWARD SPEED TESTING OF A FLAPPED WING WITH BOUNDARY LAYER CONTROL FOR USE IN DEFLECTING PROPELLER SLIPSTREAMS DOWNWARD FOR VERTICAL TAKE-OFF, PART II: TESTS AT INCIDENCE AND GROUND PROXIMITY EFFECTS NAE LR 383, National Aeronautical Establishment, National Research Council, Ottawa, Canada, July 1963, AD 417 969.

Results from tests at incidence and in the region of ground effect are presented for a large - scale, four-propeller, flapped VTOL aircraft wing model using a mobile test rig. Data are presented for two flap configurations with various amounts of blowing boundary layer control for values of the thrust coefficient from 0.6 to 1.0. A comparison of ground proximity effects over a fixed and moving ground was made, and a theory was used to predict successfully the effect of ground proximity on the thrust recovery factor and the slipstream turning angle.

Gratzer, L. B., and Odomell, T. J., DEVELOPMENT OF A BLC HIGH-LIFT SYSTEM FOR HIGH-SPEED AIRPLANES, Paper 64-589, American Institute of Aeronautics and Astronautics, Transport Aircraft Design and Operations Meeting, Seattle, Washington, 10-12 August, 1964.

Munro, N. J., LOW SPEED WIND TUNNEL EXPERIMENTS ON THICK HIGH LIFT AEROFOILS EMPLOYING BOUNDARY LAYER CONTROL BY BLOWING, Aeronautical Research Laboratories, Melbourne, Australia, September 1964.

Cockerill, J. R., STUDY OF GROUND EFFECT AND MAXIMUM LIFT ON HIGH LIFT BOUNDARY LAYER CONTROL WINGS, ERR-CL-RAZ-00-143, Canadair Limited, Subsidiary of General Dynamics, Montreal, Canada, January 1965.

Landgraf, S. K., F-4 BLC - FROM RESEARCH TO REALITY, Paper 65-714, Canadian Aeronautics and Space Institute, and American Institute of Aeronautics and Astronautics, Low-Speed Flight Meeting, Montreal, Canada 18-19, October 1965.

Arnold, K. O., INVESTIGATION IN LIFT GAIN OF A FLAPPED WING THROUGH USE OF WING-SLOT SUCTION, Zeitschrift für Flugwissenschaften, Vol. 15, February 1967, pp 37-56, in German.

Dorand, R., CONTROL BY BLOWING, OF BOUNDARY LAYER AND OF CIRCULATION, APPLIED TO FLAP ON TRAILING EDGE OF WING OR ROTOR BLADE, Giravions Dorand Co., Paris, France, 1967.

Eyre, R. C. W., and Butler, S., LOW SPEED WIND TUNNEL TESTS ON AN A. R. 8 SWEEP WING SUBSONIC TRANSPORT RESEARCH MODEL WITH BLC BLOWING OVER NOSE AND REAR FLAPS FOR HIGH-LIFT, Royal Aircraft Establishment, Farnborough, England, May 1967, AD 823 150.

Roberts, S. C., DISTRIBUTED SUCTION BOUNDARY LAYER CONTROL FOR HIGH LIFT, Conference Society of Automotive Engineers, Aeronautics and Space Engineering and Mfg. Meeting, Los Angeles, California. 7-11 October 1968.

Janour, Z., and Kocka, V., SOME RESULTS OF AERODYNAMIC RESEARCH AND FLIGHT INVESTIGATION OF THE EFFECTS OF BOUNDARY LAYER CONTROL BY BLOWING, Conference - International Council of the Aeronautical Sciences, Congress, 6th, Munich, West Germany, 9-13 September 1968.

Stewart, V. R., and Rothermel, W. T., DESIGN ANALYSIS OF DIRECT LIFT CONTROL INCORPORATION IN THE RA-5C AIRCRAFT, Report NR68H-337, North American Rockwell Corp., December 1968.

Lawford, J.A., LOW-SPEED WIND-TUNNEL TESTS ON AN UNSWEPT WING-FUSELAGE MODEL OF ASPECT RATIO 9.8, WITH TANGENTIAL BLOWING OVER TRAILING-EDGE FLAPS AND AILERONS, INCLUDING THE EFFECT OF SLIPSTREAM, RAE TR-68111, Royal Aircraft Establishment, Farnborough, England, May 1968, AD 842 609.

Tests have been made on a model fuselage with an unswept high wing of aspect ratio 9.8, with boundary layer control by blowing at the shroud of the trailing-edge flaps and ailerons. Propeller slipstream was represented during some of the tests. Critical blowing momentum coefficients ranged from 0.015 to 0.05 at flap angles of  $30^\circ$  and  $60^\circ$  respectively. A critical coefficient defined in terms of slipstream velocity at the propeller disc was substantially independent of thrust coefficient. Increments of lift coefficient, without slipstream, due to a blowing momentum coefficient of 0.1, were 0.65 and 1.82 respectively at flap angles of  $0^\circ$  and  $60^\circ$ .

## **2.7 UNIQUE DEVICES**

**Kirby, R. H., EXPLORATORY INVESTIGATION OF THE EFFECTIVENESS OF BIPLANE WINGS WITH LARGE-CHORD DOUBLE SLOTTED FLAPS IN REDIRECTING A PROPELLER SLIPSTREAM DOWNWARD FOR VERTICAL TAKE-OFF, NACA TN 3800, National Advisory Committee for Aeronautics, Washington, D. C., 1956.**

**Lockwood, V. E., Turner, T. R., and Riebe, J. M., WIND-TUNNEL INVESTIGATION OF JET-AUGMENTED FLAPS ON A RECTANGULAR WING TO HIGH MOMENTUM COEFFICIENTS, NACA TN-3865, National Advisory Committee for Aeronautics, Washington, D. C., 1956.**

**Campbell, J. P., and Johnson, J. L., WIND-TUNNEL INVESTIGATION OF AN EXTERNAL-FLOW JET-AUGMENTED SLOTTED FLAP SUITABLE FOR APPLICATION TO AIRPLANES WITH POD-MOUNTED JET ENGINES, NACA TN 3898, National Advisory Committee for Aeronautics, Washington, D. C., 1956.**

**Stalter, J. L., and Wattson, R. K., CIRCULATION CONTROL RESEARCH WIND-TUNNEL TESTS OF A POWERED-BLCWING TYPE, CIRCULATION CONTROL RESEARCH AIRPLANE MODEL PART II: EFFECT OF POWER ON THE AERODYNAMIC CHARACTERISTICS OF A CIRCULATION CONTROL RESEARCH MODEL, Report 187-2, University of Wichita, Wichita, Kansas, 1957.**

**Crabtree, L. G., and Kirby, D. A., THE ROTATING FLAP AS A HIGH-LIFT DEVICE, APPENDIX I, THEORY OF AN AEROFOIL WITH ROTATING FLAP. APPENDIX II, POWER REQUIRED TO ROTATE THE FLAP OF A TYPICAL FOUR-ENGINED TRANSPORT, TN AERO 2492, Royal Aeronautical Establishment, London, England, 1957.**

**Davenport, E. E., WIND-TUNNEL INVESTIGATION OF EXTERNAL-FLOW JET-AUGMENTED DOUBLE SLOTTED FLAPS ON A RECTANGULAR WING AT AN ANGLE OF ATTACK OF 6 DEGREES TO HIGH MOMENTUM COEFFICIENTS, NACA TN 4079, National Advisory Committee for Aeronautics, Washington, D. C., 1957.**

**Johnson, J. L., WIND-TUNNEL INVESTIGATION OF THE STATIC LONGITUDINAL STABILITY AND TRIM CHARACTERISTICS OF A SWEPTBACK-WING JET-TRANSPORT MODEL EQUIPPED WITH AN EXTERNAL-FLOW JET-AUGMENTED FLAP, NACA TN 4177, National Advisory Committee for Aeronautics, Washington, D. C., 1958.**

Johnson, J. L., WIND-TUNNEL INVESTIGATION AT LOW SPEEDS OF FLIGHT CHARACTERISTICS OF A SWEEPBACK-WING JET-TRANSPORT AIRPLANE MODEL EQUIPPED WITH AN EXTERNAL-FLOW JET-AUGMENTED SLOTTED FLAP, NACA TN 4255, National Advisory Committee for Aeronautics, Washington, D. C., 1958.

Riebe, J. M., and Davenport, E. E., EXPLORATORY WIND-TUNNEL INVESTIGATION TO DETERMINE THE LIFT EFFECTS OF BLOWING OVER FLAPS FROM NACELLES MOUNTED ABOVE THE WING, NACA TN 4298, National Advisory Committee for Aeronautics, Washington, D. C., 1958.

Anon., WIND TUNNEL TESTS ON AN AIRFOIL WITH JET BLOWING AFT OF A 22 PERCENT CHORD FLAP DEFLECTED 90 DEGREES, A TRAILING EDGE ASPIRATION SLOT, AND A LEADING EDGE SUCTION SLOT, CVAL 251, Convair Division of General Dynamics Corporation, San Diego, California, 1958.

Gainer, T. G., LOW-SPEED WIND-TUNNEL INVESTIGATION TO DETERMINE THE AERODYNAMIC CHARACTERISTIC OF A RECTANGULAR WING EQUIPPED WITH A FULL-SPAN AND AN INBOARD HALF-SPAN JET-AUGMENTED FLAP DEFLECTED 55 DEGREES, NASA MEMO 1-27-59L, National Aeronautics and Space Administration, Washington, D. C., 1959.

Helmhold, H. B., POWER REQUIREMENTS OF A BLOWING WING WITH SEALED AND SLOTTED TRAILING EDGE FLAPS, R246A-004, Fairchild Engine Airplane Corporation, March 1959.

Johnson, J. L., WIND-TUNNEL INVESTIGATION OF A SMALL-SCALE SWEEPBACK-WING JET-TRANSPORT MODEL EQUIPPED WITH AN EXTERNAL-FLOW JET-AUGMENTED DOUBLE SLOTTED FLAP, NASA Memo 3-8-59L, National Aeronautics and Space Administration, Washington, D. C., April 1959.

Wood, A. D., BRIEF EXPERIMENT OF A FLAPPED AEROFOIL HAVING A CUSPED CAVITY AND A BLOWING JET AT THE CUSP, LR 269, National Research Laboratories, Ottawa, Canada, 1959, AD 234 293.

Anon., A CONVAIR TYPE P6Y SEAPLANE MODEL WITH A COMBINED SUCTION BLOWING BLC SYSTEM AND AN ALL-BLOWING BLC SYSTEM IN COMBINATION WITH PROPELLER SLIPSTREAM, CVAL 267, Convair Division of General Dynamics Corporation, San Diego, California, 1958 thru 1960.

Turner, T. R., LOW-SPEED INVESTIGATION OF A FULL-SPAN INTERNAL-  
FLOW JET-AUGMENTED FLAP ON A HIGH WING MODEL WITH A 35 DEGREE  
SWEPT WING OF ASPECT RATIO 7.0, NASA TN D-434, Langley Research  
Center, National Aeronautics and Space Administration, Langley Station, Virginia,  
1960.

Chandivert, H. G., and Hurley, D. G., EFFECTS OF FINITE ASPECT RATIO ON  
THE PERFORMANCE OF A WING FITTED WITH A FREE-STREAMLINE FLAP,  
Aerodynamics Note 188, Aeronautical Research Laboratories, Melbourne,  
Australia, April 1961.

Alvarez-Calderon, Alberto, VTOL AND THE ROTATING CYLINDER FLAP,  
New York Academy of Sciences, Annals, Vol. 107, Art. 1, March 1963, pp 249-255.

The rotating cylinder is examined as a high-lift device for VTOL aircraft. Treated  
are a rotating cylinder at the flap as a conventional BLC device, and some of the  
STOL wind-tunnel test results. The BLC parameter for a given geometry is con-  
sidered for practical reasons as the ratio of cylinder peripheral speed  $U$  to some  
arbitrary known airspeed  $V$ . A study is made of the effect of the  $U/V$  parameter  
on a rotating cylinder in an airstream. An example is shown of the practical  
application of a rotating-cylinder flap system to the Ryan VZ-3RY twin-engine,  
deflected-slipstream, VTOL aircraft.

Neumark, S., ROTATING AEROFOILS AND FLAPS, Royal Aircraft Establish-  
ment, Farnborough, England, Royal Aeronautical Society, Journal, Vol. 67,  
January 1963.

Anon., GETOL RESEARCH PROGRAM, Convair Division of General Dynamics  
Corporation, TRECOM Technical Report 63-1, U.S. Army Transportation  
Research Command, Fort Eustis, Virginia, August 1963, AD 421 955.

Results are presented for an experimental research program to determine the  
aerodynamic characteristics of a ground-effect takeoff and landing (GETOL) air-  
craft and to ascertain the feasibility and potential of a GETOL aircraft system.  
The objective of the GETOL concept is to produce an aircraft that would eliminate  
conventional landing gear and provide a capability for takeoff and landing over  
unprepared terrain. The program included static-room and wind-tunnel testing.  
The data and results from the tests provided the basis for the design analysis  
and layouts of the GETOL aircraft study contained in this report.

White, H. E. , WIND-TUNNEL TESTS OF AN AERODYNAMICALLY CONTROLLED TILTING-WING VTOL CONFIGURATION, AERO Report 1057, David Taylor Model Basin, Washington, D.C., 1963.

Wind-tunnel tests were conducted on a model of a VTOL aircraft using a free-pivoted tilting wing with aerodynamically controlled tilt angle. The results of the test show that it is not possible to trim the pitching moment and the axial force on the wing simultaneously at all angles of wing tilt. The effect of pivot location on ability to trim is shown, and modifications to improve ability to trim are suggested.

Whittley, D. C. , THE AUGMENTOR-WING — A NEW MEANS OF ENGINE AIRFRAME INTEGRATION FOR STOL AIRCRAFT, Paper 64-574, International Council of the Aeronautical Sciences, Congress, 4th, Paris, France, August 1964.

The paper discusses recent work on the augmentor-wing, with reference to the possibility of developing the STOL aircraft to its ultimate practical limit. The basic concept is that of obtaining circulation around an airfoil by inducing flow through it. This is achieved by means of a thin primary jet located within a span-wise wing slot. Experimental work done on thrust augmentation and vectoring is described. The system is capable of generating values of maximum lift coefficient greater than the pure jet flap. Pitching moments and the efficiency of the augmentor at forward speed are discussed. Some possible applications are as a multipurpose transport and as a VTOL or STOL tactical fighter. It is considered that the augmentor-wing might also be effective in improving the marginal takeoff and landing performance of high-speed aircraft that use standard runways, and it might also be applied as a flap system for high-speed subsonic transport aircraft.

Surry, D. , CHARACTERISTICS OF A RECTANGULAR WING WITH A PERIPHERAL JET IN GROUND EFFECT, PART III, UTIAS-TN-77, Toronto University, Toronto, Canada, August 1964, AD 614 616.

Lift, drag, and pitching moment were measured on a rectangular wing with a peripheral jet in ground effect for three angles of attack, for three heights above ground, and for a range of forward speeds necessary for takeoff calculations. Nine configurations were tested in this fashion, each with different jet angles and different ratios of L. E. to T. E. jet strengths. Wherever possible, procedures were automated and on-line data reduction was used. Some flow visualization tests were made on specific configurations. The results were used to study an integrated lift and propulsion system for air-cushion takeoff and landing. These calculations showed little advantage to be gained from using variable jet strengths and angles



during takeoff at constant height when compared to fixed configuration results. The latter used angle of attack or diversion of thrust from the cushion to direct forward thrust as means for keeping the height constant. A simple takeoff procedure in which the height was allowed to increase naturally, led to slightly poorer results, but all the takeoff procedures studied provided short-field performance.

Chacksfield, J. E., INVESTIGATION OF THE POSSIBILITIES OF ROTATING CYLINDERS AS AN AUXILIARY LIFT DEVICE, Royal Aeronautical Society Journal, Vol. 68, November 1964, pp 77-780.

Stancil, R. T., and Mertaugh, L. J., ANALYSIS OF A LOW SPEED WIND TUNNEL TEST OF A HIGH MASS RATE VECTORED PROPULSION FLOW MODEL, Report 2-53310/4R-2166, Ling-Temco-Vought, Inc., Dallas, Texas, 1965, AD 613 198.

An analysis of selected portions of the data resulting from a low-speed wind-tunnel test of a semispan model of a VTOL aircraft is presented. The model features an integrated propulsion/lifting surface system as well as a horizontal tail located on an aft wing-tip extension. The propulsion system flow, simulated with cold air, exhausts over the wing trailing-edge flap (flap jet) and out of the lower surface of the wing (wing box jet). The exhaust flows can be independently vectored through 90°. Force and moment data are presented for both static and forward-flight conditions. Some comparison with theoretical predictions are presented. Portions of the data are shown with the direct thrust components removed. The results of this analysis show that: (1) the outboard location of the horizontal tail provides a reduction in airplane induced drag, (2) a significant portion of the theoretical jet-flap effect is obtained with the wing-box jet directed parallel to the wing chord plane, (3) a reduced jet-flap effect is available with deflections of the wing-box jet away from the wing chord plane, and (4) further testing is desirable for a better understanding of the characteristics of this configuration.

Mertaugh, L. J., and Davidson, J. K., ANALYSIS OF A FOLLOW-ON LOW SPEED WIND TUNNEL TEST OF A HIGH MASS RATE VECTORED PROPULSION FLOW MODEL, Report 2-53310/5R-2206, Ling-Temco-Vought Inc., LTV Vought Aeronautics Division, Dallas, Texas, July 1965, AD 619 578.

An analysis of data obtained from a second low-speed wind-tunnel test of a semispan model of a VTOL aircraft is presented. Force and moment data are presented with and without a simulated, stationary ground plane in place. Pressure data in the form of spanwise and chordwise pressure distributions are given for the wing and horizontal tail. Flow angularity measurements at the location of the horizontal tail are shown. The results of this analysis show that: (1) the maximum lift coefficient for this wing is 2.7; (2) jet-flap type pressure distributions are obtained on the wing;

(3) there is no noticeable change in wing pressure distribution due to the presence of the horizontal tail; (4) there is a 7.7-percent reduction in static thrust due to the presence of the ground board; and (5) a significant variation in the flow field in the vicinity of the tail results from the different wing configurations.

Winborn, B. R., Jr., THE PROPULSIVE WING TURBOFAN V/STOL, Paper 650-203, Society of Automotive Engineers, National Aeronautical Meeting, Washington, D. C., 1965.

This paper discusses the Air Deflection and Modulation (ADAM) concept. The V/STOL concept has been developed through adherence to a design philosophy of making each decision from the viewpoint of what is best for the overall aircraft rather than for one system, such as propulsion. A typical design for a subsonic rescue strike aircraft is described in some detail, and wind-tunnel results are discussed. Performance data are presented to the extent permitted by security classification. The aircraft is said to be versatile and highly maneuverable. Application of the ADAM concept to transport aircraft types is briefly considered.

Kikuhara, S., and Tokuda, K., A NEW STOL FLYING BOAT DESIGN, Paper 65-755, Aircraft Design and Technology Meeting, Los Angeles, California, American Institute of Aeronautics and Astronautics, Royal Aeronautical Society, and Japan Society for Aeronautical and Space Sciences, November 1965.

The aerodynamic and hydrodynamic aspects of the design of a four-engined, turbo-prop flying boat are described, drawing on the actual flight-test results of a 3/4 scale flying model. Features of the design include the adoption of the deflected slipstream and boundary layer control (BLC) as high-lift devices, automatic stability equipment, and a newly developed spray suppressor applied on the hull forebody. Test results show that the coefficient of lift is 6.9, with a takeoff run of about 400 feet in 10 seconds in an 18-knot wind. It is shown that the slow landing speed of 45 knots, together with the air-cushion effect of the BLC near the surface, reduces the landing shock to a minimum. Flight data of the model and a conventional flying boat are presented and compared, and the superiority of the new design is demonstrated. It is estimated that during the period of a year, in the North Pacific area, the craft was used for 86% of the time.

English, R. B., Brownrigg, W. E., and Davidson, J. K., DESIGN, FABRICATION, TESTING, AND DATA ANALYSIS OF ADAM II CONCEPT (PROPULSIVE WING). PART IV. TESTING IN THE LANGLEY RESEARCH CENTER 16-FOOT TRANSONIC WIND TUNNEL, LTV Aerospace Corporation, LTV Vought Aeronautics Division, Dallas, Texas, May 1966.

Rogallo, F. M. , AERODYNAMIC CHARACTERISTICS OF PROPULSIVE WING (ADAM II CONCEPT) V/STOL AIRPLANES, Langley Research Center, Langley Station, Virginia, Defense Documentation Center Summary Acc. No. NR006389, 1967.

Wind-tunnel studies were performed at subsonic speeds in FSRD facilities leading to the development and refinement of the ADAM II concept for a propulsive wing V/STOL airplane configuration. This information is required by the Air Force in order to determine the feasibility of this concept.

Whittle, D. C. , THE AUGMENTOR-WING RESEARCH PROGRAM, PAST, PRESENT AND FUTURE, Paper 67-741, Conference American Institute of Aeronautics and Astronautics, Royal Aeronautical Society, and Canadian Aeronautical and Space Institute, Anglo-American Aeronautical Conference, 10th, Los Angeles, California, 18-20 October 1967.

Kirk, J. V. , Hickey, D. H. , and Aoyagi, K. , LARGE-SCALE WIND TUNNEL INVESTIGATION OF A MODEL WITH AN EXTERNAL JET-AUGMENTED FLAP, NASA TN D-4278, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, December 1967.

An investigation has been conducted in the Ames 40- by 80-foot wind tunnel of a large-scale model powered by turbojet engines. The wing had a  $38.5^\circ$  sweep of the leading edge, an aspect ratio of 5.38, a taper ratio of 0.23, and a dihedral of  $3^\circ$ . The wings airfoil section was an NACA 65-412. The trailing-edge flaps extended from 8 to 63 percent semispan. A small auxiliary flap spanned the main flap. The exhaust from the engines was directed against the flaps to augment lift. Longitudinal aerodynamic characteristics for various combinations of main and auxiliary flap deflections are shown for thrust coefficients from 0 to approximately 1.4. Limited longitudinal and lateral-directional characteristics are shown for a simulated engine-out condition. Results also demonstrate the feasibility of using the small auxiliary flap as a means of providing direct-lift flight-path control.

Bond, W. H. , MOVING SKIN BOUNDARY LAYER CONTROL, Convair Division of General Dynamics Corporation, 1968.

Giangrande, C. , APPLICATION OF THE CALDERON FLAP TO A CARRIER-BASED JET AIRCRAFT, Report FSR-427-1, Grumann Aircraft Engineering Corporation, April 1968.

Gamse, D., and Weilberg, J.A., LARGE-SCALE WIND-TUNNEL TESTS OF AN AIRPLANE MODEL WITH TWO PROPELLERS AND ROTATING CYLINDER FLAPS, NASA TN D-4489, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, March 1968.

Whittley, D.C., LIFT AND THRUST AUGMENTATION FOR SHORT-HAUL STOLS, Space/Aeronautics, Vol. 49, June 1968, pp 92-94, 97.

## 2.8 DOWNWASH

Ribner, H.S., ON THE LIFT AND INDUCED DRAG ASSOCIATED WITH LARGE DOWNWASH ANGLES, Toronto University, Toronto, Canada, AD 162 001.

Naylor, C.H., 24-FOOT TUNNEL TESTS ON A HIGH-LIFT MODEL: DOWNWASH AND VELOCITY MEASUREMENTS AT THE TAILPLANE, Technical Report R&M 2649, Royal Aeronautical Establishment, Farnborough, England, 1951.

Morse, A., VTOL DOWNWASH IMPINGEMENT STUDY, VELOCITY SURVEY, Report 60-15, Hiller Aircraft Corp., Palo Alto, California, August 1960, AD 246 306.

White, R.P., and Vidal, R.J., STUDY OF THE VTOL DOWNWASH IMPINGEMENT PROBLEM, Report TR 60-70, Cornell Aeronautical Lab., Inc., Buffalo, New York, 1960, AD 251 154.

Intensive review and analysis were made of the problems associated with dust and debris entrainment in the downwash of helicopters and other VTOL configurations during near-ground operations. Present knowledge concerning the nature of downwash impingement is reviewed. A list and brief description are given of suggested programs which have one of the following objectives: (1) to obtain a better understanding of the problem, (2) to investigate ideas that have been proposed to reduce the entrainment and detrimental effects of particles, and (3) to investigate ideas that have been proposed for avoiding entrainment of objects by the downwash. Recommendations for a series of investigations to accomplish one or more of the above objectives are presented.

O'Bryan, T.C., AN INVESTIGATION OF THE EFFECT OF DOWNWASH FROM A VTOL AIRCRAFT AND A HELICOPTER IN THE GROUND ENVIRONMENT, NASA TN D-977, National Aeronautics and Space Administration, Washington, D.C., October 1961, AD 265 243.

Dynamic-pressure measurements, in ground effect, have been obtained about a single-rotor helicopter and a dual-propeller VTOL aircraft. The results indicate that the slipstream dynamic pressure along the ground, some distance from the center of rotation, is not a function of disk loading but merely a function of the gross weight or thrust of the aircraft. Furthermore, for a given gross weight, the thickness of this outward-flowing sheet of air is less for a small-diameter propeller (higher disk loading propeller). The variation of the dynamic-pressure flow field for single and dual propellers or rotors is significantly different in the plane of symmetry between the two rotors than in a direction normal to this plane.

The interaction of the two flows produces a region of upflow in this plane where the fuselage is located, and the decay of the maximum dynamic pressure with distance ahead of the fuselage is slower.

O'Bryan, T.C., EXPERIMENTAL STUDY OF THE EFFECT OF DOWNWASH FROM A TWIN-PROPELLER VTOL AIRCRAFT ON SEVERAL TYPES OF GROUND SURFACES, NASA TN D-1239, National Aeronautics and Space Administration, Washington, D.C., 1962.

Anon., COMPARATIVE DOWNWASH AND SIMULATED FOREST RESCUE TESTS OF THE HH-3E, HH-53B AND THE XC-142A AIRCRAFT, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, December 1967, AD 827 382.

Tests were performed with an HH-3E, an HH-53B, and an XC-142A to determine comparative downwash characteristics of the three VTOL aircraft. Simulated forest rescues were also made. Downwash velocities, sound pressure levels, temperatures, toxic hazards, and relative freedom of movement of human subjects were measured and/or observed for various hover conditions.

## 2.9 GROUND EFFECTS

Vogler, R. D., and Turner, T. R., WIND-TUNNEL INVESTIGATION AT LOW SPEEDS TO DETERMINE FLOW-FIELD CHARACTERISTICS AND GROUND INFLUENCE ON A MODEL WITH JET-AUGMENTED FLAPS, NACA TN 4116, National Advisory Committee for Aeronautics, Washington, D. C., 1957.

Newsom, W. A., EFFECT OF GROUND-PROXIMITY ON AERODYNAMIC CHARACTERISTICS OF TWO HORIZONTAL-ATTITUDE JET VERTICAL-TAKE-OFF-AND-LANDING AIRPLANE MODELS, NASA TN D-419, National Aeronautics and Space Administration, Washington, D. C., 1960.

Putman, W. F., RESULTS OF EXPERIMENTS ON A TILT-WING AIRCRAFT USING THE PRINCETON UNIVERSITY FORWARD FLIGHT FACILITY, Princeton Report 542, Princeton University, Princeton, New Jersey, 1961.

Colin, P. E., A PRELIMINARY INVESTIGATION ON V/STOL MODEL TESTING FOR GROUND PROXIMITY EFFECTS, ASTIA No. N63-10028, 1962.

Colin, P. E., GROUND PROXIMITY AND THE VTOL AIRCRAFT, AGARD Report 409, Advisory Group for Aeronautical Research and Development, Paris, France, 1962.

Anon., EXTRACTS FROM THE FIRST AND SECOND RECOMMENDATIONS OF THE ACOA TO THE TECHNICAL ADVISORY PANEL OF THE NATIONAL AERONAUTICAL RESEARCH COMMITTEE, Associate Committee on Aerodynamics, National Research Council, Ottawa, Canada, May 1964, AD 447 541.

First recommendation - The effects of ground proximity, ground roughness, and low-level turbulence on the aerodynamic characteristics of VTOL-STOL aircraft and gems, the problems of unsteady aerodynamics associated with separated flow including the determination of flutter derivatives, fundamental aerodynamics of internal flow particularly as related to duct losses and peripheral jets, the aerodynamics of jets and jet sheets, the Coanda effect and the augmentation of jet thrust, theoretical and experimental information on the aerodynamic characteristics of propellers at all angles of attack, the interactions between the propulsive airstream and the wing, and boundary layer control to suppress separation using both geometric and aerodynamic means. Second recommendation - High-speed aerodynamics.

Anon., GROUND EFFECTS ON V/STOL AND STOL AIRCRAFT, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1965.

Ground effects on V/STOL and STOL aircraft arise from the fact that these aircraft support themselves by deflecting air downward with attendant effects on both the ground and the aircraft. The effects of self-generated turbulence will not be serious if adequate control is provided, and this annoyance to the pilot can be reduced by providing artificial damping. The avoidance of ground-erosion damage involves proper preparation and housekeeping of the landing site for high-disk-loading vehicles and proper operating procedures to avoid running into debris. Research is still in progress to obtain a better understanding of hot-gas ingestion and means of reducing it.

Foshag, W.F., LITERATURE SEARCH AND COMPREHENSIVE BIBLIOGRAPHY OF WINGS IN GROUND EFFECT AND RELATED PHENOMENA, David Taylor Model Basin, Washington, D.C., March 1966, AD 633 139.

A comprehensive survey and literature search is made of the general field of wings operating in ground effect and related phenomena. Comments are included on some of the papers published, to present a sketch of the methods of approach of a number of authors. The bibliography presents sources which consider the problem from the theoretical, experimental, and/or applications point of view. Tables are included which provide a convenient breakdown of the various sources, for a quicker method of locating specific references dealing with an area of special interest to the reader.

Anon., INVESTIGATION OF GROUND EFFECTS ON LATERAL DIRECTIONAL CONTROL ON THE 1/11-SCALE MODEL OF THE XC-142 V/STOL TRANSPORT, Langley Research Center, National Aeronautics and Space Administration, Defense Documentation Center Summary Acc. No. NR003681, Langley Station, Virginia, April 1966.

The problem of poor handling qualities in ground effect is presented. Investigations were continued to give some insight into the cause of an accident with the XC-142 V/STOL airplane during a landing in which there appeared to be loss of control.

Goodson, K.W., GROUND EFFECTS ON A FOUR-PROPELLER TILT-WING CONFIGURATION OVER A FIXED AND MOVING GROUND PLANE, NASA TN D-3938, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, May 1967.



A wind-tunnel investigation of a four-propeller tilt-wing V/STOL configuration in ground proximity with and without ground-plane boundary layer has been conducted. Tests were made at transition-speed conditions to determine the effect of ground proximity and the effect of ground-plane boundary layer on the measured aerodynamic results. The investigation showed that considerable reductions in lift and drag coefficients occur for some wing-flap angle combinations when the tilt-wing configuration is moved into ground proximity under near-equilibrium thrust conditions. The adverse effects of the ground on the lift coefficients are intensified under accelerating thrust conditions. Under accelerating conditions, the drag coefficient is also further reduced, and this reduction should aid the acceleration. For high-lift high-thrust conditions, the presence of a boundary layer on the wind-tunnel ground plane causes a reduction in the lift and drag coefficients in ground effect for the tilt-wing configuration. Effects of ground-plane boundary layer are evident in both the tail-off and tail-on pitching moments. The results show that wind-tunnel ground-effect tests of tilt-wing configurations should be made with ground-plane boundary layer removed if ground-effect aerodynamic characteristics are to be simulated, especially for high-lift high-thrust conditions.

Goodson, K.W., EFFECTS OF GROUND PROXIMITY ON THE LONGITUDINAL LATERAL AND CONTROL AERODYNAMIC CHARACTERISTICS OF A TILT-WING FOUR-PROPELLER V/STOL MODEL, NASA TN D-4237, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, December 1967.

A wind-tunnel investigation of a four-propeller tilt-wing V/STOL configuration was conducted to determine the longitudinal, lateral, and control aerodynamic characteristics in ground proximity. The tests were made using the moving-belt ground plane. The investigation showed that reductions in lift and drag occurred on the tilt-wing configuration when in ground proximity. Smoke flow observations showed that ground proximity caused slipstream to be deflected forward of the model. At certain ground heights and wing-tilt-flap-deflection angles, these self-generated disturbances became quite erratic. For some wing flap angle combinations, the unsteady flow caused erratic yawing moments at 0° sideslip. Smoke flow observations also showed that the ground-height-to-chord ratio at which the onset of flow recirculation occurred was proportional to the ratio of disk loading to free-stream dynamic pressure. The extent of the recirculation in front of the wing was dependent upon the wing tilt angle at a given flap deflection and ground height. Ground proximity reduced the aileron yaw control by about 50 percent for the design condition ( $\delta_{aL} = 50^\circ$  is the left-wing aileron deflection) at the lowest ground height of the tests. Increasing the aileron deflection to  $\delta_{aL} = -70^\circ$ , a 0.10-chord upper-surface spoiler increased the control yawing moment to about 70 percent of original out-of-ground-effect value obtained with  $\delta_{aL} = -50^\circ$ . Ground proximity also considerably reduced the adverse rolling moment due to aileron deflection for yaw control.

Putman, W. F., AN EXPERIMENTAL INVESTIGATION OF GROUND EFFECT ON A FOUR-PROPELLER TILT-WING V/STOL MODEL, Princeton University, USAAVLABS Technical Report 68-45, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, July 1968, AD 673 824.

Tests were conducted on a one-tenth scale model of a tilt-wing V/STOL at specified points simulating flight conditions at various heights above the ground. The model was moved at selected velocities through still air; and lift, drag, and pitching moment were measured at various heights above the ground. Investigations included combinations of 30°, 40°, and 60° wing incidence angle with 30°, 40°, and 60° flap deflection, and thrust coefficients ranging from 0.80 to 0.95. Model ground clearances of 3.5 to 36 inches were investigated both at constant altitude and with the altitude continuously varying during the run. The data are presented as plots of lift, drag, and pitching moment coefficients. Also included are data from wind-tunnel tests on similar models. A brief analysis is made of ground effect phenomena, and an understanding of the general data trends is obtained. The magnitude and direction of the force change in ground effect are predictable. However, the pitching moment change is strongly influenced by factors such as the flow field beneath the fuselage, the change in downwash at the horizontal tail, and other effects.

### **3. THEORETICAL, SEMIEMPIRICAL, AND ANALYTICAL METHODS FOR PREDICTING V/STOL AIRCRAFT PERFORMANCE**

#### **3.1 GENERAL**

Allen, H.J., CALCULATION OF THE CHORDWISE LOAD DISTRIBUTION OVER AIRFOIL SECTIONS WITH PLAIN, SPLIT, OR SERIALLY-HINGED TRAILING-EDGE FLAPS, NACA TR 634, National Advisory Committee for Aeronautics, Washington, D.C., 1938.

Heaslet, M.A., and Pardee, O., CRITICAL MACH NUMBERS OF THIN AIRFOIL SECTIONS WITH PLAIN FLAPS, NACA ACR A6A30 (WR W-2), National Advisory Committee for Aeronautics, Washington, D.C., April 1946.

DeYoung and Harper, THEORETICAL SYMMETRIC SPAN LOADING DUE TO FLAP DEFLECTION FOR WINGS OF ARBITRARY PLAN FORM AT SUBSONIC SPEEDS, NACA TR 1071, National Advisory Committee for Aeronautics, Washington, D.C. 1952.

Sivells, J.C., and Westrick, G.C., METHOD FOR CALCULATING LIFT DISTRIBUTION FOR UNSWEPT WINGS WITH FLAPS OR AILERONS BY USE OF NONLINEAR SECTION LIFT DATA, NACA TR 1090, National Advisory Committee for Aeronautics, Washington, D.C., 1952.

Lowry and Polhamus, A METHOD FOR PREDICTING LIFT INCREMENTS DUE TO FLAP DEFLECTION AT LOW ANGLES OF ATTACK IN INCOMPRESSIBLE FLOW, NACA TN 3911, National Advisory Committee for Aeronautics, Washington, D.C., 1957.

James, H.A., and Hunton, L.W., ESTIMATION OF INCREMENTAL PITCHING MOMENTS DUE TO TRAILING EDGE FLAPS ON SWEPT AND TRIANGULAR WINGS, NACA TN 4040, National Advisory Committee for Aeronautics, Washington, D.C., July 1957.

Mathias, G., ON THE OPTIMUM UTILIZATION OF AN AIRPLANE HIGH-LIFT DEVICE FOR MINIMUM TAKE-OFF RUN AND CLIMB DISTANCE, Zeitschrift fur Flugwissenschaften, Vol. 9, September 1961.

Jacob and Riegels, THE CALCULATION OF THE PRESSURE DISTRIBUTION OVER AIRFOIL SECTIONS OF FINITE THICKNESS WITH AND WITHOUT FLAPS AND SLATS, RAE Library Trans #101, 1963.

Mair, W.A., and Edwards, R.J., A PARAMETRIC STUDY OF TAKE-OFF AND LANDING DISTANCES FOR HIGH-LIFT AIRCRAFT, ARC 25173, Royal Aeronautical Establishment, Farnborough, England, 1965.

Takeoff and landing distances have been calculated for a wide range of distances. The maximum speed lift coefficient is shown to be a function of aspect ratio and thrust/weight ratio, almost independent of wing loading.

McDonald, J.W., and Stevens, J.R., SUBSONIC LIFTING SURFACE DESIGN AND ANALYSIS PROCEDURE, Report NOR 66-206, Northrop Corp., Hawthorne, Calif., April 1965.

Powell, B.J., THE CALCULATION OF THE PRESSURE DISTRIBUTION OF A THICK CAMBERED AEROFOIL AT SUBSONIC SPEEDS INCLUDING THE EFFECTS OF THE BOUNDARY LAYER, ARC CP 1005, Aeronautical Research Council, London, England, 1967, AD 837 316.

This paper describes a method for calculating the pressure distribution on the surface of a two-dimensional aerofoil of arbitrary shape in subsonic flow, taking into account the presence of a boundary layer on the surface of the aerofoil. The effect of the boundary layer is accounted for by considering the inviscid flow over a displacement surface made up of the aerofoil section shape, the boundary layer displacement thickness, and the wake. A simple model of the wake is introduced, and it is shown that provided certain simple conditions are satisfied in the region near the aerofoil trailing edge, the pressure distribution predicted is not unduly sensitive to the detailed development of the wake. The method has been developed using techniques which make it very suitable for computation on a digital computer. Calculations have been made of the pressure distribution on an RAE 101 aerofoil section at incidence for which measured boundary layer data were available, and also in the case of a heavily cambered aerofoil at incidence using theoretically predicted boundary layer characteristics. The comparison between the experimental and predicted pressure distributions shows good agreement in both cases.

Lenhart, R.F., LOW SPEED WING LIFT TESTS, Princeton University, Office of Naval Research, Washington, D.C., Defense Documentation Center Summary Acc. No. DN623846, August 1967.

This analytical and experimental investigation was made to develop techniques for predicting specific aerodynamic characteristics for aircraft in low-speed flight. Particularly where extremely high values of lift coefficient were involved, the investigation was concerned with the problem of determining the effect on aerodynamic circulation of the fuselage, and the detailed distribution of lift between the wing and fuselage for various configurations.

Kisielowski, E., GENERALIZED ROTOR PERFORMANCE, Vertol Div., The Boeing Co., U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, February 1967, AD 648 874.

Roberts, S.C., EVALUATION METHODS FOR COMPARISON OF THE AERODYNAMIC CHARACTERISTICS OF VARIOUS V/STOL AIRCRAFT, Mississippi State University, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, Defense Documentation Center Summary Acc. No. DA0A4020, 1968.

Ruppert, P.E., and Saaris, G.R., A GENERAL THREE-DIMENSIONAL POTENTIAL FLOW METHOD APPLIED TO V/STOL AERODYNAMICS, SAE Paper 680304, Conference Society of Automotive Engineers, Air Transportation Meeting, New York, New York, 29 April - 2 May 1968.

Ellison, D.E., and Malthan, L., USAF STABILITY AND CONTROL DATCOM, McDonnell Douglas Corp., Douglas Aircraft Division, Long Beach, California, August 1968.

Sanders, K.L., HIGH-LIFT DEVICES, A WEIGHT AND PERFORMANCE TRADE-OFF METHODOLOGY, Paper 761, Society of Aeronautical Weight Engineers, 1969.

### 3.2 DEFLECTED SLIPSTREAM

Rethorst, S., LIFT ON A WING IN A PROPELLER SLIPSTREAM AS RELATED TO LOW-SPEED FLIGHT, Aero. Eng. Review, Vehicle Research Corporation, Pasadena, California, 1956.

Kirby, R. H., STABILITY AND CONTROL OF PROPELLER-DRIVEN TRANSPORT VTOL AIRPLANES, American Helicopter Society, Inc., May 1957, pp. 43-50.

Kuhn, R. E., TAKE-OFF AND LANDING DISTANCE AND POWER REQUIREMENTS OF PROPELLER-DRIVEN STOL AIRPLANES, Aero. Eng. Rev., Vol. 16, No. 11, November 1957, pp. 38-42.

Kuhn, R. E., SEMIEMPIRICAL PROCEDURE FOR ESTIMATING LIFT AND DRAG CHARACTERISTICS OF PROPELLER-WING-FLAP CONFIGURATIONS FOR VERTICAL AND SHORT-TAKE-OFF AND LANDING AIRPLANES, NASA Memo 1-16-59L, National Aeronautics and Space Administration, Washington, D. C., 1959.

Rethorst, S., Royce, W. W., Strand, T., Fujita, T., Johnson, D., and Szentjobbi, P., DEVELOPMENT OF METHODS FOR PREDICTING V/STOL AIRCRAFT CHARACTERISTICS, Report 5, Vehicle Research Corporation, Pasadena, Calif., April 1960.

Kuhn, R. E., REVIEW OF BASIC PRINCIPLES OF V/STOL AERODYNAMICS, NASA TN D-733, National Aeronautics and Space Administration, Washington, D. C., 1961.

Anon., AERODYNAMICS OF DEFLECTED SLIPSTREAMS: PART I. FORMULATION OF THE INTEGRAL EQUATIONS, Cornell Aeronautical Laboratory, TRECOM Technical Report 61-32, U.S. Army Transportation Research Command, Fort Eustis, Virginia, October 1961.

Rethorst, S., Fujita, T., Szentjobbi, P., Sollow, P., Bettes, W., and Dougherty, J., DEVELOPMENT OF METHODS FOR PREDICTING V/STOL AIRCRAFT CHARACTERISTICS, Report 12, Vehicle Research Corporation, Pasadena, Calif. December 1961.

Cumberbatch, R., A LIFTING SURFACE THEORY FOR WINGS AT HIGH ANGLES OF ATTACK EXTENDING THROUGH MULTIPLE JETS, Report 9, Vehicle Research Corp., Pasadena, California, 1963, AD 1423 274.

This report consists of the first and second parts of the three part analytical portion of the high angle of attack theory (third phase) of VRC's program of developing methods for assessing the nonuniform flow fields of wing-propeller slipstream aerodynamics. The three parts of the third-phase effort are comprised of: (1) wings located at various heights in the jet, (2) highly cambered wings as used in deflected slipstream V/STOL arrangements, and (3) tilt-wing configurations where the jet is at an angle to the free-stream flow. The present report contains the basic theoretical development of the first two parts enumerated above. This portion of the third phase effort has greatly extended the applicability of the analysis by encompassing deflected slipstream V/STOL arrangements under development.

Limmel, P.D., ESTIMATION OF TAKEOFF GROUND-RUN DISTANCES FOR JET-PROPELLED CONVENTIONAL AND STOL AIRCRAFT, IRM 37, Operations Evaluation Group, Office of the Chief of Naval Operations, Washington, D.C., April 1963, AD 408 661.

Wu, T. Yao Tsu, A LIFTING SURFACE THEORY FOR WINGS AT HIGH ANGLES OF ATTACK EXTENDING THROUGH INCLINED JETS, VRC-9a, Vehicle Research Corp., Pasadena, California, October 1963, AD 426 715.

Lifting surface theory for wings extending through propeller slipstreams based on the Rethorst Solution has been extended to encompass the effect of jets inclined to the free-stream flow. This extension permits the prediction of spanwise lift distribution and induced drag of tilt-wing and deflected slipstream V/STOL aircraft over the entire flight spectrum, from hovering to cruise. It is demonstrated that the effect of inclined jets on wing characteristics may be determined by applying appropriate boundary conditions (as derived in the present analysis) to the existing formulations enumerated above. The simplicity thus obtained results in a major reduction of numerical work and extends the usefulness of all phases of the program.

Thibault, E.A., ESTIMATION OF STOL A/C TAKE-OFF DISTANCES, NAVWEPS R5 64 17, Analysis Division, Bureau of Naval Weapons, Hydroballistics Advisory Committee, Washington, D.C., 1964.

The study was undertaken to find an easy-to-use takeoff distance prediction method and to evaluate its applicability to STOL aircraft. For the purposes of the study, STOL aircraft were defined as those requiring a takeoff ground roll of less than 1000 feet. Two existing takeoff ground roll estimate methods were evaluated by comparing predicted values with available data for several STOL aircraft. The resulting accuracies were respectively within 9% and 11% error.

It was found that one of these methods could be further simplified and yet still yield acceptable results. That is, excluding two predictions, this simplified method yielded an accuracy within 13% error. In addition, some correlation was found to exist between short takeoff ground roll and total distance over a 50 foot obstacle. As a result, an expression was derived relating the two.

Goland, L., Miller, N., and Butler, L., EFFECTS OF PROPELLER SLIPSTREAM ON V/STOL AIRCRAFT PERFORMANCE AND STABILITY, Report DCR-137, Dynasciences Corp., Fort Washington, Pennsylvania, August 1964.

Presented is an analytical investigation of the aerodynamic forces acting on wing-propeller combinations including the effects of propeller slipstreams. The results of the developed theory are then applied to typical two- and four-propeller VTOL and STOL wing configurations. Correlation with existing test data is shown to be satisfactory. Consideration is also given to such associated items as the effects of the slipstream on (1) wing stall, (2) aircraft takeoff and landing performance, and (3) aircraft stability and control.

Fowler, H.D., DETERMINATION OF BREGUET 941 STOL AIRCRAFT TRANSITION VELOCITIES WITH VARIOUS FLAP DEFLECTIONS, SAE Paper 960C, Society of Automotive Engineers, International Automotive Engineering Congress, Detroit, Michigan, January 1965.

A method for calculating the transitional velocities associated with various flap deflections for the Breguet 941 deflected-slipstream STOL is described. Basic lift and drag curves of the Breguet type of triple-slotted flaps are developed, and accurate power and thrust levels for takeoff, climb, and stall are determined. The vital role of induced drag due to flaps is clarified, and the effect of the thrust coefficient on the lift of the wing with zero flap deflection is evaluated. In addition, the drag caused by the slipstream dynamic pressure over the wing is found. Transitional velocities for climb, takeoff, and landing are calculated, and formulas are presented for determining the takeoff and landing distances for this type of aircraft. The calculations are found to agree well with flight test data.

Templin, R.J., A MOMENTUM RULE FOR OPTIMUM AIRCRAFT PERFORMANCE IN THE V/STOL TRANSITION REGIME, LR-470, National Aeronautical Establishment, Ottawa, Canada, January 1967, AD 819 596.

Ellis, N.D., A COMPUTER STUDY OF A WING IN A SLIPSTREAM-DESCRIPTIVE NOTE, Report UTIAS TN-101, Toronto University, Ontario, February 1967.



A FORTRAN IV program for the IBM 7094-11 digital computer has been formulated based on a theory of wing-slipstream interference by Ribner which accounts for the slipstream effects by means of a vortex sheath. This sheath together with the wing vorticity leads to a pair of simultaneous integral equations for the unknown circulations. A stepwise approximation of the circulations reduces the pair to a system of linear algebraic equations. The format has been modified from that of the earlier work to facilitate inversion of the equations by computer. This first program has been restricted for simplicity to the case of a slipstream centered on a rectangular wing. The printout yields circulation, span loading, integrated lift, and other properties. The results show a progression from approximately 'slender body theory' for very narrow slipstreams to 'strip theory' for very broad slipstreams and compare well with experimental data.

George, M., and Kisielowski, E., INVESTIGATION OF PROPELLER SLIPSTREAM EFFECTS ON WING PERFORMANCE, Report DCR-234, Dynasciences Corporation, Blue Bell, Pennsylvania, November 1967, AD 666 247.

A theoretical and experimental study was conducted to determine the effects of propeller slipstream on wing performance. Previously developed theoretical analyses were expanded and modified to account for radial variation of the propeller slipstream velocity. The experimental program consisted of wind-tunnel tests conducted with a motor-propeller system mounted on a semispan wing model. The wing model used has a chord to propeller diameter of 0.46, an aspect ratio of 6.37 (3.18 for semispan), a taper ratio of 1.0, and an NACA 0015 airfoil section. The wing model has eight floating wing segments with and without a 45° simulated split flap. Located within each floating wing segment is a three-component strain gage balance to provide measurements of lift, drag, and pitching moment. The measurements of total wing lift, drag, and pitching moment were obtained with the six-component main wind-tunnel balance. The test data obtained included the effects of the variation of propeller slipstream velocity by using two propellers of different geometries. Propeller rotation for all tests was down at the wing tip. The experimental and theoretical results are compared; in general, good correlation is observed.

Levinsky, E. S., Thommer, H. U., Yager, P. M., and Holland, C. H., LIFTING SURFACE THEORY AND TAIL DOWNWASH CALCULATIONS FOR V/STOL AIRCRAFT IN TRANSITION AND CRUISE, USAAVLABS Technical Report 68-67, Air Vehicle Corp., U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, October 1968, AD 680 969.

A large tilt-angle lifting-surface theory is developed for tilt-wing and tilt-propeller/rotor V/STOL aircraft. The method is based on an inclined actuator disc analysis

in which closed-form solutions are obtained for the velocity potential at large distances behind the actuator surface. Both the normal velocity and the nonlinear pressure boundary conditions are satisfied exactly across the slipstream interface. The inclined actuator disc analysis is combined with a discrete-vortex Weissinger-type lifting surface theory. Wing-propeller combinations at arbitrary wing angle of attack, propeller tilt angle, and thrust coefficient are considered. Multiple slipstream effects including a slipstream rotation are introduced. Agreement between theory and experiment is shown to be satisfactory for small slipstream inclination angles. However, at large angles, the theory (with an undeformed, but displaced, slipstream and wake) predicts significantly lower downwash angles in the tail region than shown by the test data, possibly due to slipstream deformation and wake roll-up. Use of only one-half the calculated wake displacement gave improved agreement at these conditions. However, insufficient data are available for making a general evaluation of the theory at large angles. Extensive digital computer results are given in chart form, showing span loading, downwash angle, stability parameter, and dynamic pressure at arbitrary points behind the wing for V/STOL configurations with two and four slipstreams.

### **3.3 TILT WING**

Guerrieri, M.A., and Stuart, J., III., A SIMPLIFIED THEORETICAL INVESTIGATION OF A WING-PROPELLER COMBINATION THROUGH A RANGE OF ANGLES-OF-ATTACK FROM ZERO DEGREES TO 90 DEGREES, AND A COMPARISON WITH EXPERIMENTAL RESULTS, Eng. Report 461.31, Hiller Helicopters, 1955.

Cromwall, C.H., A STABILITY ANALYSIS OF TILT-WING AIRCRAFT, Princeton Report 477, Princeton University, Princeton, New Jersey, May 1960.

Hargraves, C.R., AN ANALYTICAL STUDY OF THE LONGITUDINAL DYNAMICS OF A TILT-WING VTOL, Princeton Report 561, Princeton University, Princeton, New Jersey, 1961.

Neal, B., and Lyster, H.N.C., ESTIMATION OF MINIMUM FIELD REQUIREMENTS OF TWO OVERLOADED, PROPELLER-DRIVEN, TILT-WING VTOL AIRCRAFT (INCLUDING THE EFFECTS OF FLAP SETTING, RUNWAY SURFACE, WIND, WING TILT RATE AND FLAP BOUNDARY LAYER CONTROL), NAE LR-373, National Aeronautical Establishment, National Research Council, Ottawa, Canada, January 1963, AD 405 740.

Minimum takeoff and landing distances are calculated for two overloaded, propeller-driven, tilt-wing VTOL aircraft. The effects of flap setting, runway surface, wing tilt rate and flap boundary layer control are considered at various thrust-to-weight ratios. It appears that takeoff and landing over a 50-foot obstacle can be achieved in 400 feet at an all-up-weight 60 percent greater than the VTO all-up-weight.

Strand, T., UNIFIED PERFORMANCE THEORY FOR V/STOL AIRCRAFT IN EQUILIBRIUM LEVEL FLIGHT, Report 358, Air Vehicle Corp., La Jolla, California, May 1966.

A unified V/STOL performance theory of equilibrium level flight is developed. The theory is applicable for wings in the presence of slipstreams and is based upon an analysis of minimum induced drag for a given airplane weight. The theory has been correlated with existing test results on a number of different V/STOL aircraft by presenting lift/drag and nondimensional power-required curves versus nondimensional velocity. In general, close agreement between theory and experiment is found over the entire velocity range from cruise to hover.

**Beppu, G., and Curtiss, H.C., AN ANALYTICAL STUDY OF FACTORS INFLUENCING THE LONGITUDINAL STABILITY OF TILT-WING VTOL AIRCRAFT, Princeton University, USAAVLABS Technical Report 66-53, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, July 1966, AD 640 945.**

An analytical method for predicting the stability characteristics of tilt-wing VTOL aircraft in the transition speed range is presented. Sample calculations based on an assumed tilt-wing VTOL transport configuration of the XC-142A class with double-slotted flaps are given. Particular emphasis is placed on the sensitivity of the results to various assumptions made in the analysis. The contributions of the various aircraft components and the aerodynamic interactions of the components to the stability derivatives are discussed, as well as the changes in the characteristic modes of motion of the vehicle that result from variations in the stability derivatives. The trim conditions of the vehicle are shown to be quite sensitive to the prediction of the flap characteristics. A comparison of the calculated results with experimental data obtained from a dynamic model of the XC-142A indicates that the trends of the stability derivatives are correctly predicted. The agreement between theory and experiment is good in hovering; however, as the wing incidence is reduced, the difference between theory and experiment becomes quite large.

**Chambers, J.R., and Grafton, S.B., CALCULATION OF THE DYNAMIC LONGITUDINAL STABILITY OF A TILT-WING V/STOL AIRCRAFT AND CORRELATION WITH MODEL FLIGHT TEST, NASA TN D-4344, National Aeronautics and Space Administration, Washington, D.C., February 1968.**

### **3.4 TILT AND DUCTED PROPELLERS**

**Shenkman, A.M., GENERALIZED PERFORMANCE OF CONVENTIONAL PROPELLERS FOR VTOL/STOL AIRCRAFT, Report HS 1829, Hamilton Standard, Windsor Locks, Connecticut, March 1958, AD 161 494.**

**Sinacori, J., and Lange, A., THEORETICAL INVESTIGATION OF DUCTED PROPELLER AERODYNAMICS, Vol. IV, Republic Aviation Corporation, Farmingdale, New York, AD 266 422.**

The performances of VTOL aircraft using ducted and free propellers are compared on the basis of existing light VTOL aircraft equipped with ducted propellers and of the same aircraft using free propellers computed for this purpose. The free propellers appear to provide better aircraft performance, especially higher flight speed. An appraisal and analysis of VTOL aircraft based on the existing VTOL testbeds forms the second part of this volume. Summaries of design particulars and performance are given in graphical and tabular form. Special-purpose vehicles, such as the flying jeeps, aerial platforms, and aerodynes, are treated as a separate group. Particular performance data of the various VTOL aircraft are collected in an appendix.

**Grunwald, K.J., and Goodson, K.W., DIVISION OF AERODYNAMIC LOADS ON A SEMISPAN TILTING-DUCTED PROPELLER MODEL IN HOVERING AND TRANSITION FLIGHT, NASA TN D-1257, National Aeronautics and Space Administration, Washington, D.C., May 1962.**

**Erickson, J.C., Ladden, R.M., Borst, H.V., and Ordway, D.E., A THEORY FOR VTOL PROPELLER OPERATION IN A STATIC CONDITION, VTOL Systems Division of Curtiss-Wright Corporation, Caldwell, New Jersey, October 1965, AD 623 527.**

A general theory for performance calculations was formulated based on a continuous vortex representation along the lines of the classical lifting-line model. As opposed to forward flight, the deformation of the wake is appreciable just behind the propeller, and its determination constitutes the heart of the static problem. A computer program has been developed to calculate both the inflow at the propeller and the induced velocity at any field point for an arbitrary description of the trailing vortex sheets. To approximate the force-free condition imposed on the wake, an initial wake hypothesis derived from the theory of the generalized actuator disk was first used. The resulting comparisons with both detailed and gross measurements were unsatisfactory, and a refined hypothesis was derived.

The refined wake hypothesis provides a more reasonable representation of the pitch of the elements of the deformed trailing vortex sheets as well as the envelope of their trajectories.

Huang, K. P., Goland, L., and Balin, I., CHARTS FOR ESTIMATING AERODYNAMIC FORCES ON STOL AIRCRAFT WINGS IMMERSED IN PROPELLER SLIPSTREAM, Report DCR-161, Dynasciences Corporation, Fort Washington, Pennsylvania, November 1965.

Equations and charts are presented for estimating the lift and longitudinal force coefficients of V/STOL aircraft wings immersed in propeller slipstreams. Sample calculations are made, and the results show fair to good correlation with available experimental data. The effect of many design and operating parameters is analyzed.

Greenberg, M. D., and Ordway, D., A THREE-DIMENSIONAL THEORY FOR THE DUCTED PROPELLER AT ANGLE OF ATTACK, Report TAR-TR-6509, Therm Advanced Research, Inc., Ithaca, New York, December 1965, AD 480 994.

An inviscid theory is developed for the steady aerodynamic loading on a ducted propeller in forward flight at angle of attack. As a first approximation, the problem is regarded as the superposition of the given ducted propeller at zero incidence and a cylindrical duct of the same aspect ratio but of zero thickness and camber at the given incidence. This approximation is then improved to include the cyclic variation of the blade loading. Not only are the normal force and pitching moment changed, but also a finite side force and yawing moment, unknown heretofore, are found. Explicit formulas are given to carry out numerical calculations, and a limited comparison with experimental results shows good agreement.

Matsuoka, K., Takahasi, M., and Yonezawa, H., AERODYNAMIC CHARACTERISTICS OF PROPELLER-WING FLAP SYSTEMS, *Int - Osaka Prefecture, University, Bulletin, Series A, Engineering and Natural Sciences*, Vol. 17, No. 1, 1968, pp 65-78.

Anon., AERODYNAMIC PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT, Vol. I, Propeller and Rotor Aerodynamics, AD 657 562; Vol. II, Propulsion and Interference; Vol. III, Aerodynamic Research on Boundary Layers, AD 567 564; Vol. IV, Panels on Recommended V/STOL Aerodynamic Research, Panel Summaries, Featured Speakers, and Technical Paper Discussions, AD 567 565, CAL/USAAVLABS Symposium Proceedings, Cornell Aeronautical Lab., Inc., Buffalo, New York, June 1966.

The following technical papers were presented: Aeronautical Research Requirements as Determined from the X-19 and X-100 VTOL Programs, Thoughts on Progress

in Rotating-Wing Aerodynamics, Some Possibilities for Research on Stability and Control at STOL Flight Speeds, Aerodynamic Research - Improvements of the Tilt-Wing Concept, Aerodynamic Problem Areas of V/STOL Aircraft and Recommended Research, A Discussion of Low-Speed VTOL Aerodynamic Problems and Suggestions for Related Research, Areas of Fruitful Research and Development for Rotary Wing Aircraft, A Comeback of Low-Speed Aerodynamics Research, Required Aerodynamic Research for V/STOL Aircraft, Low-Speed Aerodynamic Problems Associated with Helicopters and V/STOL Aircraft, Selected Research Results and Recommendations for Aerodynamic Research, and Recommendations for Aerodynamic Research on Helicopters and V/STOL Aircraft.

McKinney, M. O., AERODYNAMICS AND STABILITY AND CONTROL OF ROTOR POWERED V/STOL AIRCRAFT, Langley Research Center, Langley Station, Virginia, Defense Documentation Center Summary Acc. No. NR000502, March 1967.

The objective of the program was to determine the aerodynamic and stability and control characteristics of various VTOL aircraft configurations such as tilt rotor, unloaded rotor, and stopped rotor configurations that are powered by rotors for hovering flight but are capable of much higher speeds than pure helicopters..

Bielkiewicz, P., A SIMPLE GRAPHICAL METHOD FOR EVALUATING THE EFFECT OF THRUST VECTOR TILT ON THE AIRCRAFT PERFORMANCE, AFIT TR 68-6, Air Force Institute of Technology, School of Engineering, Wright-Patterson AFB, Ohio, July 1968.

The semigraphical method presented in the report may be useful for the preliminary performance computation for an aircraft with the variable thrust axis tilt. Application to different flight problems is shown. Optimization of some flight parameters can be achieved by simple graphical construction.

Statler, I. C., V/STOL AIRCRAFT STABILITY AND CONTROL CHARACTERISTICS STUDY, Cornell Aeronautical Lab., Inc., Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, Defense Documentation Center Summary Acc. No. DF 476396, April 1969.

The objective of the program is the development of analytical engineering methods for evaluating the aerodynamic stability and control characteristics of V/STOL aircraft. The X-22A vehicle will be examined in detail. These methods are to be developed in a manner that will avoid the limitations of the classic methods.

Church, R. M. W., A METHOD FOR THE CALCULATION OF FORCE, MOMENT AND POWER COEFFICIENTS OF PROPELLERS IN FORWARD FLIGHT AT TILT ANGLES FROM 0 TO 90 DEGREES, Technical Note AL-119, Navy Ship Research and Development Center, Carderock, Maryland, April 1969.



### 3.5 JET FLAP

Kuechemann, D., A METHOD FOR CALCULATING THE PRESSURE DISTRIBUTION OVER JET-FLAPPED WINGS, Royal Aircraft Establishment, Farnborough, England, 1956.

Strand, T., JET FLAP-SPAN LOAD AND PITCHING MOMENT, ZA-257, Convair Division of General Dynamics Corporation, San Diego, California, January 1957.

Draper, J., A JET WING PERFORMANCE AND STABILITY PROCEDURES, R246-004, Fairchild Engine Airplane Corp., Hagerstown, Maryland, April 1958.

Maskell, E.C., and Spence, D.A., A THEORY OF THE JET FLAP IN THREE DIMENSIONS, RAE AERO 2612, Royal Aircraft Establishment, Farnborough, England, September 1958.

Hartunian, R.A., THE FINITE ASPECT RATIO JET FLAP, A1-1190-A-3, Cornell Aeronautical Lab., Inc., Buffalo, New York, October 1959.

Wiss. Ges. Luftfahrt, LIFTING SURFACE THEORY FOR WINGS WITH JET FLAPS, Transl. into English from JAHR. 1960, National Research Council, Ottawa, Canada, 1964.

Korbacher, G.K., and Sridhar, K., NOTE ON THE TOTAL DRAG OF JET FLAPPED WINGS, Report 64, Toronto University, Institute of Aerophysics, May 1960.

Yoler, Y.A., A LIFTING LINE THEORY OF THE JET FLAPPED WING, Report 24, Flight Sciences Lab., Boeing Scientific Research Laboratories, Seattle, Washington, January 1960.

Taylor, A.S., THEORETICAL INVESTIGATION OF THE LONGITUDINAL STABILITY, CONTROL AND RESPONSE CHARACTERISTICS OF JET-FLAP AIRCRAFT, PARTS I AND II, RM 3272, Aeronautical Research Council, Great Britain, 1962.

Williams, J., Butler, S.F.J., and Wood, M.N., THE AERODYNAMICS OF JET FLAPS, Advances in Aeronautical Sciences, Vol. 4 - 2nd International Congress in the Aeronautical Sciences, Pergamon Press, Inc., 1962, pp 619-656.

Korbacher, G.K., JET FLAP CHARACTERISTICS FOR HIGH-ASPECT-RATIO WINGS, ALAA Journal, Vol. 2, January 1964, pp. 64-71.

The thrust hypothesis, its concept, and its experimental verification are discussed. Characteristics for jet-flapped wings at zero and nonzero angle of attack are also presented. It is indicated that any combination of jet-flap parameters, such as jet deflection angle, rate of blowing, and angle of attack, which produces a desired lift may be read directly from such characteristics. Furthermore, the characteristics convey data on the economy and efficiency of lift production. An operating line can be added to the characteristics, if lift production is optimized with respect to jet blowing rates and wing drag. Logically, the range of most economical jet-flap operation coincides with that portion of the characteristics over which any increment in jet-flap momentum causes exactly the same increment in propulsive thrust. Over this portion, three "constants," relating the total jet-flap drag to the total lift, are known. In addition, the application of the jet-flap principle to STOL aircraft design is discussed.

Wynanski, I., and Newman, B.G., THE EFFECT OF JET ENTRAINMENT ON LIFT AND MOMENT FOR A THIN AEROFOIL WITH BLOWING, Aeronautical Quarterly, Vol. 15, May 1964.

Jet flap theory for thin airfoils is extended to include the effect of jet entrainment on the external flow when the jet is blown over the upper surface of the airfoil. The effective camber of the airfoil is increased by the sink effect due to entrainment, and the increase of lift at zero incidence is proportional to the square root of the jet momentum coefficient. Formulas and charts are presented to facilitate the determination of the increments of lift and pitching moment due to this effect. The theory is shown to be in first-order agreement with the exact solution for a circular-arc airfoil of small camber with distributed sinks on the upper surface. The new theory is compared with four old sets and one new set of experimental data. It greatly improves the accuracy of prediction for cases where the incidence and flap angle are small. The new theory substantiates the usefulness of a small flap in applications of the jet-flap principle.

Hope, C.D., AN EXPERIMENTAL INVESTIGATION INTO THE SHAPE OF THRUST AUGMENTING SURFACES IN CONJUNCTION WITH COANDA DEFLECTED JET SHEETS, University of Toronto, Part I, July 1964, UTIAS TN 70; Part II, January 1965, UTIAS TN 79, T. Mehus.

Korbacher, G.K., PERFORMANCE, OPERATION AND USE OF LOW ASPECT RATIO JET FLAPPED WINGS, Report 97, Toronto University, Institute for Aerospace Studies, Toronto, Canada, May 1964.

The characteristics of a jet-flapped wing of aspect ratio 6 for STOL application are presented, discussed, and evaluated. As is the case for high-aspect-ratio ( $AR = 20$ ) jet-flapped wings, the study has shown that a range for most economical jet-flap operation is well defined. The angle of attack as an efficient means of lift production loses its usefulness with low-aspect-ratio jet-flapped wings, whereas the optimum jet deflection angle seems hardly to be affected. The most efficient jet-flap application for STOL is considered to call for a complete integration of the lifting and propulsive systems. In the range of most economical jet-flap operation, semi-empirical relationships are said to predict parameter changes accurately enough.

Benner, S.D., THE COANDA EFFECT AT DEFLECTION SURFACES WIDELY SEPARATED FROM THE JET NOZZLE, UTIAS TN NO. 78, University of Toronto, Toronto, Canada, April 1965.

Lissaman, P.B.S., A LINEAR THEORY FOR THE JET FLAP IN GROUND EFFECT, Paper 67-2, American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 5th, January 23-26, New York, 1967.

### **3.6 BOUNDARY LAYER CONTROL**

Riebe, J. M. , A CORRELATION OF TWO-DIMENSIONAL DATA ON LIFT COEFFICIENT AVAILABLE WITH BLOWING, SUCTION, AND PLAIN-FLAP HIGH-LIFT DEVICES, NACA RM L55D29a, National Advisory Committee for Aeronautics, Washington, D. C. , 1955.

Kelly, M. W. , ANALYSIS OF SOME PARAMETERS USED IN CORRELATING BLOWING-TYPE BOUNDARY LAYER CONTROL DATA, NACA RM A56F12, National Advisory Committee for Aeronautics, Washington, D. C. , 1956.

Malavard, L. , et al. , THEORETICAL AND EXPERIMENTAL INVESTIGATION OF CIRCULATION CONTROL, Report 358, Princeton University, Princeton, New Jersey, July 1956.

Butler, S. F. J. , and Williams, J. , AERODYNAMIC ASPECTS OF BOUNDARY LAYER CONTROL FOR HIGH LIFT AT LOW SPEEDS, AGARD Report 414, Advisory Group for Aeronautical Research and Development, Paris, France, January 1963.

de B Edwards, R. R. , STUDY OF THE POWER SYSTEMS REQUIRED FOR BOUNDARY LAYER CONTROL FOR LOW DRAG AND HIGH LIFT, Canadair Limited, Subsidiary of General Dynamics Corporation, Montreal, Canada, April 1965.

Cockerill, J. R. , STUDY OF BOUNDARY LAYER CONTROL FOR HIGH LIFT, RAZ-00-125, Canadair Limited, Subsidiary of General Dynamics Corporation, Montreal, Canada, April 1965.

Kikuhara, S. , and Kasu, M. , DESIGN OF BLOWING TYPE BLC SYSTEM ON JAPANESE STOL SEAPLANE, Shin-Meiwa Industry Co. , Ltd. , Symposium on Subsonic Aeronautics, New York, 1967.

### **3.7 TUNNEL WALL EFFECTS**

**Kuhn, R. E., and Naeseth, R., TUNNEL-WALL EFFECTS ASSOCIATED WITH V/STOL-STOL MODEL TESTING, AGARD Report 303, Advisory Group for Aeronautical Research and Development, Paris, France, March 1959.**

Wind-tunnel investigations of VTOL and STOL airplane models involve configurations in which a large amount of power is being used to generate part of the lift through the propeller slipstreams or jet exhausts directed downward at large angles to the free-stream direction. For many configurations, the propellers or jet exhausts are arranged, for example, as in the jet flap, to cover the entire span of the wing and thus to assist the wing in its natural process of producing so called 'circulation' lift. This arrangement results in the streamlines in the vicinity of the wing also being turned through large angles to the free-stream direction of flow. The presence of the tunnel walls, however, imposes the conditions that the streamlines at the tunnel walls must be parallel to the free stream. Thus, the problem of tunnel-wall effects in VTOL/STOL model testing is similar to that associated with conventional model testing but differs greatly in degree. Experience has shown that, in addition to these usual tunnel-wall effects, flow separation on the model can also be induced by the tunnel walls. The experiences of the Langley Research Center of NASA related to these problems in closed-throat wind tunnels are reviewed.

**Heyson, H. H., TABLES OF INTERFERENCE FACTORS FOR USE IN WIND-TUNNEL AND GROUND-EFFECT CALCULATIONS FOR VTOL-STOL AIRCRAFT, National Aeronautics and Space Administration, Washington, D. C., January 1962.**  
**PT. 1 - WIND TUNNELS HAVING WIDTH-HEIGHT RATIO OF 2.0, NASA TN D-933,**  
**PT. 2 - WIND TUNNELS HAVING WIDTH-HEIGHT RATIO OF 1.5, NASA TN D-934,**  
**PT. 3 - WIND TUNNELS HAVING WIDTH-HEIGHT RATIO OF 1.0, NASA TN D-935,**  
**PT. 4 - WIND TUNNELS HAVING WIDTH-HEIGHT RATIO OF 0.5, NASA TN D-936.**

**Heyson, H. H., LINEARIZED THEORY OF WIND-TUNNEL JET-BOUNDARY CORRECTIONS AND GROUND EFFECT FOR VTOL-STOL AIRCRAFT, NASA TR R-124, National Aeronautics and Space Administration, Washington, D. C., 1962.**

**Williams, J., Butler, S. F., FURTHER DEVELOPMENTS IN LOW-SPEED WIND TUNNEL TECHNIQUES FOR V/STOL AND HIGH-LIFT MODEL TESTING, RAE-TN-AERO-2944, Royal Aircraft Establishment, Farnborough, England, January 1964.**

**Olcott, J. W., A SURVEY OF V/STOL WIND TUNNEL WALL CORRECTIONS AND TEST TECHNIQUES, Princeton Report 725, Princeton University, Princeton, New Jersey, December 1965.**

A discussion of wind tunnel boundary corrections as they apply to VTOL model testing is presented. Conventional wall correction theory is inadequate since it fails to account for both the presence of a highly developed wake and the total lift acting on the model. Correction theories that do consider the lift and wake characteristics of VTOL designs give satisfactory results, provided there is no wake distortion due to the interference of tunnel walls. Both the Heyson and Kirkpatrick VTOL boundary correction theories are examined and their limitations discussed. A comparison of free air and tunnel results for a 0.165 scale North American Aviation tilt wing design and a free air study of an early Hamilton Standard XC-142 propeller model are discussed. The propeller data agreed with theoretically predicted values, but discrepancies, particularly in drag force, appeared when the airship North American Aviation data were compared with similar tunnel results. The exact cause of the differences was not determined. The importance of the VTOL model wake is substantiated. Minimum tunnel sizes necessary to avoid wake impingement and disturbance are presented.

Grunwald, K.J., and Heyson, H. H., WIND TUNNEL BOUNDARY INTERFERENCE FOR V/STOL TESTING, IN NASA AMES RESEARCH CENTER CONF. ON V/STOL AND STOL AIRCRAFT, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, 1966.

Joppa, R., WIND-TUNNEL JET-BOUNDARY CORRECTIONS FOR V/STOL MODELS, University of Washington, Seattle, Washington, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, Defense Documentation Center Summary Acc. No. NR000495, March 1967.

Objectives are to improve the accuracy of V/STOL wind-tunnel tests, develop improved understanding of wall effects, devise improved correction theories, and develop test section configurations that minimize wall effects.

Heyson, H.H., TABLES OF INTERFERENCE FACTORS FOR USE IN CORRECTING DATA FROM VTOL MODELS IN WIND TUNNELS WITH 7 BY 10 PROPORTIONS, NASA SP-3039, National Aeronautics and Space Administration, Washington, D. C., 1967.

Heyson, H.H., SOME CONSIDERATIONS IN WIND-TUNNEL TESTS OF V/STOL MODELS, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, Presented at the University of Tennessee Space Institute, Tullahoma, Tennessee, 29 September 1967.

Considerable care is required in applying wall interference corrections to V/STOL data. The following items comprise a minimum list of features which should be considered: type of tunnel and proportions, effective wake skew angle, span of both

lifting-angle-of-attack pivot location and center-of-gravity location. Auxiliary balances may be required to obtain the forces of each component in complex lifting systems. Some discrepancies may remain, largely because of the imperfect knowledge of the aerodynamics of many V/STOL configurations. The boundary layer on the tunnel floor requires careful consideration, particularly in ground-effect testing. Recirculation will limit the minimum speeds at which successful data can be obtained. Many questions, such as the effect of angular and velocity rates, remain to be answered in evaluating V/STOL testing techniques.

South, P., MEASUREMENTS OF THE INFLUENCE OF MIXED BOUNDARIES ON THE AERODYNAMIC CHARACTERISTICS OF A V/STOL WIND TUNNEL MODEL, IN AGARD Fluid Dynamics of Rotor and Fan Supported Aircraft at Subsonic Speeds, National Aeronautical Establishment, Ottawa, Canada, September 1967.

Lift, drag, pitching moment, propeller thrust, and flow angle in the region of the tailplane were measured for a twin-propeller tilt-wing aircraft model in 15-foot-diameter open and closed working sections and in a number of 7-foot-square sections. The wall effects were deduced by comparing the data from the 7-foot-square sections with a set of reference data obtained by averaging the results of the tests in the 15-foot open and closed working sections. For the completely open and completely closed working sections, the results are compared with the corrections predicted by Heyson's method. The tests in the mixed boundary working sections show that it is possible to greatly reduce the effect upon angle of attack by using suitable working sections and that it is also possible to modify the dynamic pressure effects but that mixed boundaries are not as effective in reducing the latter effects.

Matthews, G. B., and Hardy, G. S., WIND TUNNEL WALL EFFECTS IN V/STOL MODEL TESTING, University of Virginia, Charlottesville, Virginia, NASA CR-66721, National Aeronautics and Space Administration, Washington, D. C., July 1968.

Wind-tunnel wall effects in V/STOL model testing are caused by the large deflection angles of the slipstream from the high lift propulsion devices in transition from hover to high-speed flight. Accurate representation of the path of the slipstream wake is useful in computing wall effects. The present report is a refinement and verification of Kirkpatrick's method of wind tunnel corrections for V/STOL model testing representing the entrainment of free stream air and the actual path of the slipstream wake. Results are presented showing effects on the path of revisions in Kirkpatrick's jet analysis and comparisons of the computed path with new data as well as with existing data.

Wright, R. H., TEST SECTIONS FOR SMALL THEORETICAL WIND-TUNNEL-BOUNDARY INTERFERENCE ON V/STOL MODELS, National Aeronautics and Space Administration, Langley Research Center, Langley Station, Virginia, August 1968.

### 3.8 DOWNWASH

Martin, J. F., A PROPOSAL FOR SOLUTION OF THE TILT WING V.T.O. L. AIRCRAFT DOWNWASH PROBLEM BASED ON ANALYSIS OF NASA DATA, RAX-84-107, Canadair Limited, Subsidiary of General Dynamics Corporation, Montreal, Canada, 1960.

Ribner, H.S., ON THE LIFT AND INDUCED DRAG ASSOCIATED WITH LARGE DOWNWASH ANGLES, Toronto University, Toronto, Canada, AD 162 001.



#### 4. HANDLING CHARACTERISTICS OF V/STOL AIRCRAFT

McKinney, M.O., et al, DYNAMIC STABILITY AND CONTROL CHARACTERISTICS OF A CASCADE-WING VERTICALLY RISING AIRPLANE MODEL IN TAKE-OFFS, LANDINGS, AND HOVERING FLIGHT, NACA TN-3198, National Advisory Committee for Aeronautics, Washington, D.C., June 1954.

McCormick, B.W., UNSTEADY FLIGHT PROBLEMS OF THE TILTING WING PROPELLER AIRCRAFT, Vertol Report R-78, Vertol Aircraft Corporation, Morton, Pennsylvania, July 1956.

Tapscott, R.J., CRITERIA FOR PRIMARY HANDLING QUALITIES CHARACTERISTICS OF VTOL AIRCRAFT IN HOVERING AND LOW-SPEED FLIGHT, NASA Conference on V/STOL Aircraft, National Aeronautics and Space Administration, Washington, D.C., 1960.

Anderson, S.B., AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT, NASA TN D-331, National Aeronautics and Space Administration, Washington, D.C., 1960.

Madden, J., Droll, J., and Neil, D., A STUDY OF V/STOL FLYING QUALITIES REQUIREMENTS, Report 2023-917001, Bell Aerosystems, Buffalo, New York, 1960.

Curtiss, H.C., SOME BASIC CONSIDERATIONS REGARDING LONGITUDINAL DYNAMICS OF AIRCRAFT AND HELICOPTERS, Princeton Report 562, Princeton University, Princeton, New Jersey, 1961.

Garren, J.F., Jr., EFFECTS OF GYROSCOPIC CROSS COUPLING BETWEEN PITCH AND ROLL ON THE HANDLING QUALITIES OF VTOL AIRCRAFT, NASA TN D-812, National Aeronautics and Space Administration, Washington, D.C., 1961.

Garren, J.F., Jr., EFFECTS OF GYROSCOPIC CROSS COUPLING BETWEEN PITCH AND YAW ON THE HANDLING QUALITIES OF VTOL AIRCRAFT, NASA TN D-973, National Aeronautics and Space Administration, Washington, D.C., 1961.

Drinkwater, F.J., III, OPERATIONAL TECHNIQUE FOR TRANSITION OF SEVERAL TYPES OF V/STOL AIRCRAFT, NASA TN D-774, National Aeronautics and Space Administration, Washington, D.C., 1961.

Williamson, G. A., DYNAMIC STABILITY ANALYSIS OF A VTOL VECTORED-SLIPSTREAM VEHICLE DURING TRANSITION, Princeton Report 535, Princeton University, Princeton, New Jersey, 1961.

Ellis, D. P., Carter, G. A., A PRELIMINARY STUDY OF THE DYNAMIC STABILITY AND CONTROL RESPONSE DESIRED FOR V/STOL AIRCRAFT, Princeton Report 611, Princeton University, New Jersey, 1961.

Reeder, J. P., HANDLING QUALITIES EXPERIENCE WITH SEVERAL VTOL RESEARCH AIRCRAFT, NASA TN D-735, National Aeronautics and Space Administration, Washington, D. C., 1961.

All of the VTOL research aircraft discussed successfully demonstrated conversion from hovering to airplane flight and vice versa. However, control about one or more axes of these aircraft was inadequate in hovering flight. Furthermore, ground interference effects were severe in some cases and accentuated the inadequacy of control in hovering and very low speed flight. Stalling of wing surfaces resulted in limitations in level-flight deceleration and in descent, particularly for the tilt-wing aircraft. Minor modifications to the wing leading edge produced surprisingly large and encouraging reductions in adverse stall effects. Height control in hovering and in low-speed flight proved to be a problem for the aircraft not having direct control of the pitch of the rotors. The other systems showed undesirable time lags in development of a thrust change.

Henderson, C., Kroll, J. and Hesby, A., CONTROL CHARACTERISTICS OF V/STOL AIRCRAFT IN TRANSITION, Report 2023-917002, Bell Aerosystems, Buffalo, New York, 1962.

Anon., RECOMMENDATIONS FOR V/STOL HANDLING QUALITIES, AGARD Report 408, North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Paris, France, October 1962, AD 410 323.

This report presents recommendations of a working group sponsored by the AGARD flight mechanics panel on desirable handling qualities for military V/STOL aircraft. The recommendations, which are necessarily tentative, particularly as regards their application to large aircraft, are based in some respects on requirements for U.S. military helicopters, but considerable use has been made of the results of flight assessments of handling qualities of a number of V/STOL research aircraft. To improve their validity, they should be kept under continual review by critical, systematic comparison with the accepted handling qualities of as many new V/STOL aircraft as possible.

Quigley, H.C., and Innis, R.C., HANDLING QUALITIES AND OPERATIONAL PROBLEMS OF A LARGE FOUR-PROPELLER STOL TRANSPORT AIRPLANE, NASA TN D-1647, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, 1963.

A flight investigation has shown that a 100,000-pound transport airplane equipped with blowing boundary-layer control on highly deflected flaps, drooped ailerons, and control surfaces can take off and land over a 50-foot obstacle in less than 1,500 feet and at speeds of less than 65 knots. It is indicated that some standard operational techniques and procedures should be changed for STOL operation. The airplane had satisfactory longitudinal and unsatisfactory lateral-directional handling qualities.

Anon., FLIGHT CONTROL SYSTEMS FOR VTOL TRANSPORT AIRCRAFT, Interavia, Vol. 18, February 1963, pp 188 and 189.

Problems involved in the flight control of multiengined V/STOL transport aircraft, particularly in the hover and transition modes, are discussed. It is seen that explorations of numerous designs aimed at meeting all the requirements with one simple control system in each aircraft axis, comparable to current aircraft installations, are unsuccessful. Reasons for this are advanced. It is proposed, in conjunction with the force and moment control systems, to install engine pneumatic group thrust compensators (GTC) in each wing. The GTC is specified as a simple, reliable pneumatic device which is dependent only upon the presence of engine thrust. Examination of a number of flight-control-system layouts leads to the conclusion that the most effective scheme is a system offering full authority force and moment control without stabilizer veto. The major elements of the operation of the flight system are described.

Griffith, J.H., PROPOSED VTOL FLIGHT REQUIREMENTS, New York Academy of Sciences, Annals, Vol. 107, Art. 1, March 1963.

Proposed requirements are presented for VTOL transport aircraft, representing the thinking in the flight-test branch of the FAA. Definitions are given as follows: (1) VTOL, vertical takeoff and landing aircraft which can hover out of ground effect over a given position in no wind; (2) STOL, short takeoff and landing aircraft which are capable of flight slower than power-off stall speed, with engine power augmenting aerodynamic lift (e.g. boundary-layer control, tilted, or directed thrust) and (3) minimum operating speed, speed from which a safe landing can be made with the critical engine inoperative. Requirements are then proposed in detail for performance, controllability, stability, and stalling characteristics.

Brul, E. T., A SIMULATOR STUDY OF TILT-WING HANDLING QUALITIES, Grumman Aircraft Engineering Corp., Bethpage, New York, March 1963.

An experimental investigation was performed to study handling qualities of tilt-wing type VTOL aircraft. A flight simulator consisting of a cockpit free to pitch and roll, and an optical motion in the remaining four degrees of freedom, was employed in this program. Control sensitivity and rate damping requirements about each axis at hover were investigated relative to the performance of maneuvering tasks that require, in general, more positive control applications than trimming and more finely coordinated multiple control utilization than single-degree-of-freedom move and stop maneuvers. That handling qualities requirements depend upon the maneuver in later sophistication is clearly suggested by comparing the results of the present study with published NASA data representing the extremes in time characteristics, as well as control, aerodynamic rate, and gyroscopic coupling. The results of the control response-time variations are most interesting, for they suggest that the criterion upon which present helicopter specifications are based (i.e., time to reach proper direction of acceleration) is inadequate.

Quigley, H.C., and Lawson, H.F., SIMULATOR STUDY OF THE LATERAL-DIRECTIONAL HANDLING QUALITIES OF A LARGE FOUR-PROPELLERED STOL TRANSPORT AIRPLANE, NASA TN D-1773, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California, 1963.

The lateral and directional stability and control characteristics of a large four-propellered STOL transport airplane (the boundary-layer-control equipped NC-1308) have been studied on the landing approach simulator to determine changes in the characteristics that might be required to achieve satisfactory lateral-directional handling qualities. The study has shown that the handling qualities can be improved by increased directional stability and damping. A large increase in stability in conjunction with increased yaw rate damping gave some improvement, but the reduced directional response to rudder inputs prevented the configuration from being rated satisfactory by the evaluating pilots. A satisfactory configuration was achieved by doubling the basic directional stability and including a damping term which gave yawing moments proportional to rate change of sideslip.

Lollar, T.E., A RATIONALE FOR THE DETERMINATION OF CERTAIN VTOL HANDLING QUALITIES CRITERIA, AGARD Report 471, Advisory Group for Aeronautical Research and Development, Paris, France, July 1963.

Described are the results obtained in VTOL handling quality studies using fixed-base simulators under instrument flight conditions. Simulation techniques

that give reliable results when operated by experienced pilots are described. The approach to handling-qualities criteria is made using servomechanism techniques and measurements of the pilot describing function. Good correlation between the derived control system parameter boundaries of this report and flight test data on variable-stability VTOL aircraft is shown. Analysis of the closed-loop airplane-pilot system showed a lower bound on airplane damping of 0.75/sec to ensure tolerable closed-loop stability for instrument flight conditions. For light stick forces there is an optimum pilot gain of approximately 10 in. of stick deflection per radian of attitude error. The maximum practical pilot gain is 60 in/rad. These pilot gain values, coupled with crossover frequency criteria, form boundaries in terms of airplane damping and control sensitivity.

Dathe, H. M., REVIEW OF HOVERING CONTROL REQUIREMENTS FOR VTOL AIRCRAFT BY A FLIGHT DYNAMICS ANALYSIS, AGARD Report 472, Advisory Group for Aeronautical Research and Development, Paris, July 1963.

In accordance with the AGARD recommendations for handling qualities in hovering flight, the control power and the control thrust requirements for aircraft gross weights between 1 and 100 tons are estimated using statistical data for the moment of inertia. These results are compared with an analysis of the aircraft motions following disturbances and control inputs and with maneuverability. The effects of damping, dead time, gust level, etc., are investigated, and some control system design criteria are obtained.

Martin, J. F., and Michaelsen, O. E., THE AERODYNAMIC APPROACH TO IMPROVED FLYING QUALITIES OF TILT-WING AIRCRAFT, Paper 63-484, American Institute of Aeronautics and Astronautics, Canadian Aeronautics and Space Institute, and Royal Aeronautical Society, Anglo-American Conference, 9th, Cambridge, Mass., and Montreal, Canada, 1963.

Aerodynamic and control system problems associated with tilt-wing V/STOL aircraft in hovering and transition are examined. Among the areas discussed are longitudinal flight, in terms of the control of flow separation up to high angles of attack, the minimization of out-of-trim pitching moment, and the provision of an adequate and satisfactory control system.

Drinkwater, F. J., III, Rolls, L. S., Turner, H. L., and Quigley, H. C., V/STOL HANDLING QUALITIES AS DETERMINED BY FLIGHT TEST AND SIMULATION TECHNIQUES, International Council of the Aeronautical Sciences, Congress, 3rd, Stockholm, Sweden, 1964, pp 307-322.

The control-power and damping requirements are investigated for V/STOL aircraft, using a variable stability and control Bell X-14A test vehicle. The X-14A is a low-winged, jet-propelled aircraft which derives its vertical lift ability from the jet exhaust of two turbojet engines. Satisfactory and unacceptable boundaries for control along the pitch, roll, and yaw axes, as evaluated by test pilots, are presented. In addition, a chart based on flight-test performance measurements is presented showing takeoff speed plotted against ground-run time for various values of thrust/weight ratio, thrust vector angle, and takeoff distance. The results of tests with the deflected-slipstream Ryan VZ-3 and with the boundary-layer control Lockheed C-130 B are also reviewed.

Henshaw, D.H., and Colavincenzo, O.M.S., THE STEADY STATE LATERAL CONTROL EQUATIONS WITH PARTICULAR REFERENCE TO STOL AIRCRAFT, Canadian Aeronautics and Space Journal, Vol. 10, March 1964, pp 67-71.

Presented is an evaluation of lateral control equations for application to short take-off and landing (STOL) aircraft. Problems are analyzed by introduction of two reference frames, one fixed in space and the other, with origin at the aircraft center of gravity and fixed with respect to the aircraft, establishing a stability axis system, which is in fact a set of coordinate systems. Study of the equations as applied to various flight conditions indicates that a general solution would be highly complex and that STOL aircraft may be subject to major control problems.

Schumacher, P.W.J., and Wilson, E.K., QUALITATIVE EVALUATION OF INSTRUMENT FLIGHT AND ALL WEATHER OPERATION CHARACTERISTICS OF THE BREGUET 941 AIRCRAFT, ASD TDR64-79, Aeronautical Systems Div., Air Force Systems Command, Wright-Patterson AFB, Ohio, March 1964.

The Breguet 941-01 aircraft and its instrument flying capability were evaluated. The aircraft was easy to fly, and landing in the STOL configuration from a GCA can be made safely, reliably, and without difficulty. Several deficiencies which existed in the aircraft were scheduled to be studied and/or corrected by the contractor following the test program. Maintainability of the aircraft was good. The propulsion system, the cross-shafting, and the brakes operated trouble-free. The aircraft has potential as an excellent assault transport for operation from prepared and unprepared landing strips.

Castle, R.A., Gray, A.L., and McIntyre, W., SIMULATION OF HELICOPTER AND V/STOL AIRCRAFT, VOLUME III, PART 1. COMPUTATION METHODS ANALOG. STUDY, EQUATIONS OF MOTION OF VERTICAL/SHORT TAKE-OFF AND LANDING OPERATIONAL FLIGHT/WEAPON SYSTEM, Melpar Inc., Falls Church, Virginia, May 1964, AD 607 737.

This report demonstrates methods of mechanizing the equations of motion of helicopters and V/STOL aircraft by the use of analog computing equipment. The report reviews and discusses criteria for the selection of analog computer type as 60 cycle and 400 cycle, and choice of carrier, as well as specific computer components. A helicopter and a tilt-wing V/STOL are selected for computer mechanization, and the computer flow diagrams which may be typical computer diagrams used in the analog simulation of such aircraft are discussed.

Carpenter, D. O., and Jenny, R. B., STATISTICAL APPROACH TO LOW SPEED CONTROL CRITERIA FOR V/STOL AIRCRAFT, Paper 64-286, American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D. C., July 1964.

V/STOL control criteria are analyzed statistically using characteristics satisfactory for STOL, SFA, and VTOL aircraft. Data from industry and NASA are correlated and compared with criteria from helicopter specification MIL-H-8501A, NATO AGARD Report 408, and conventional fixed-wing specification MIL-F-8785. The variation of control criteria with gross weight is found to fluctuate approximately according to the relationship  $(GW + 1000)^{-1/3}$ . V/STOL aircraft control criteria are somewhat greater than those found acceptable for helicopters. The analysis shows the roll control power to be twice the IFR helicopter requirement, and pitch and yaw criteria to be about 1.5 and 1.0 times the IFR helicopter requirements, respectively.

Miller, D. P., and Clark, J. W., RESEARCH ON METHODS FOR PRESENTING VTOL AIRCRAFT HANDLING QUALITIES CRITERIA, Paper 64-618, American Institute of Aeronautics and Astronautics, Transport Aircraft Design and Operations Meeting, Seattle, Washington, August 1964.

Analytical and flight simulator studies were conducted to examine the effects on selection of optimum longitudinal control sensitivity of (1) the oscillatory mode dynamics; (2) the stability derivatives  $M_q/I_y$ ,  $X_u/m$ , and  $M_{\dot{u}}g/I_y$ ; and (3) the level of turbulence. A method for presenting handling qualities criteria was developed and is described, which permits construction of the optimum longitudinal control sensitivity line on a plot of pitch rate damping vs longitudinal control sensitivity for any aircraft for which  $X_u/m$  and  $M_{\dot{u}}g/I_y$  are known or can be estimated. Predictions of the optimum longitudinal control sensitivity line based on contours established using the UAC V/STOL aircraft flight simulator are in good agreement with published flight test data for the NASA X-14A VTOL research aircraft and the Princeton HUP-1 variable-stability helicopter. It is concluded that the stability derivatives and the level of turbulence have significant and systematic effects on optimum longitudinal handling qualities, and a basis is provided for correlating criteria for aircraft having widely different aerodynamic, mass, and inertial characteristics.

Wilson, R.K., and Westbrook, C.B., HANDLING QUALITIES OF VTOL AIRCRAFT, Paper 64-777, American Institute of Aeronautics and Astronautics, Military Aircraft System and Technology Meeting, Washington, D.C., September 1964.

Problem areas in the design and development of VTOL's are discussed. The problem of the deficient status of handling qualities criteria is said to be compounded by a number of mutually related problem areas. These problem areas include: a lack of reliable aerodynamic data on VTOL vehicles in hover, transition, and ground effect; a deficiency in analysis techniques; a lag in simulation capability; and a lack of operational experience with VTOL vehicles. A history of failures in VTOL programs is outlined, and the development of handling qualities criteria is described. Vehicle dynamics and pilot vehicle analysis methods are considered; the problems and benefits that accrue with the use of wind-tunnel facilities are outlined; and other areas, including control-display, approach, and landing, are considered. Four new VTOL research vehicles are reportedly expected to provide needed experimental data. Necessary research efforts are indicated.

Anon., RECOMMENDATIONS FOR V/STOL HANDLING QUALITIES WITH AN ADDENDUM CONTAINING COMMENTS ON THE RECOMMENDATIONS, AGARD Report 408A, North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Paris, France, October 1964, AD 661 748.

The recommendations, which are necessarily tentative, particularly as regards their application to large aircraft, are based in some respects on requirements for U.S. military helicopters, but considerable use has been made of the results of flight assessments of handling qualities of a number of V/STOL research aircraft. To improve their validity, they should be kept under continual review by critical, systematic comparison with the accepted handling qualities of as many new V/STOL aircraft as possible.

Miller, R.H., ADVANCED FLIGHT CONTROL SYSTEM CONCEPTS FOR VTOL AIRCRAFT. PHASE I, Massachusetts Institute of Technology, TRECOM Technical Report 64-50, U.S. Army Transportation Research Command, Fort Eustis, Virginia, October 1964, AD 609 553.

Described are the results of a research program to develop practical control systems providing optimum control characteristics for VTOL aircraft under all conditions. Control system requirements are developed from an analysis of the VTOL flight control problem. Possible advanced system concepts are described, and the evaluation of these concepts using a fixed-base flight simulator is reported. The results indicate the desirability of controlling ground velocity during hovering



and low-speed flight, and aircraft altitude during cruise flight. The analytical design of a self-contained inertial velocity measuring system to provide the required indication of ground velocity is presented. The design of an experimental flight control system for a tandem-rotor helicopter is described in detail, and a flight test program to evaluate the control system concepts using the experimental equipment is outlined.

Garren, J.F., Kelley, J.R., and Reeder, J.P., EFFECTS OF GROSS CHANGES IN STATIC DIRECTIONAL STABILITY ON V/STOL HANDLING CHARACTERISTICS BASED ON A FLIGHT INVESTIGATION, NASA TN D-2477, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, October 1964.

A flight investigation utilizing a variable-stability helicopter was conducted in order to determine the effects of gross changes in static directional stability on V/STOL handling qualities and on requirements for directional sensitivity and damping during low-speed operation. Tasks under both simulated instrument and visual conditions were for evaluation of the handling characteristics provided by various combinations of static directional stability. Minimum satisfactory levels of directional sensitivity and damping correspond to current criteria.

Brenckmann, M., IMPROVEMENTS IN LONGITUDINAL STABILITY AND CONTROL DURING THE LANDING APPROACH OF STOL AIRCRAFT, Paper 64-804, American Institute of Aeronautics and Astronautics and Canadian Aeronautics and Space Institute, Joint Meeting, Ottawa, Canada, October 1964.

An analytical definition is given of the short-field landing characteristics of an STOL experimental aircraft as determined by performance studies, maneuver dynamics analysis, and flight simulation. The effort was directed not so much toward improving unacceptable control behavior as toward defining control modes best suited to the achievement of optimum and consistent landing performance. Factors of flight accuracy and piloting factors affecting the landing distances are described. The control modes, stability of the control loops, and analog simulation applied to a modified DHC Otter are discussed in detail. Several tasks were investigated by simulating flight with or without automatic control: (1) returning to a fixed approach path after a step gust disturbance, (2) maintaining a fixed approach path in random longitudinal or normal turbulence, and (3) maintaining a fixed approach path in wind-shear and turbulence. Transitions into the approach and between several approach paths were also briefly explored. It was found that the directional task of holding a straight approach was quite difficult on the simulator and required an appreciable learning time. Further, it was noted that experience also had an influence, since nonpilot operators required more learning time on this particular aspect than professional test pilots.

For an approach in random turbulence using the three modes of control (with three degrees of freedom), pilots' opinions of fully manual control, automatic elevator control, and automatic thrust control were, respectively: a difficult task requiring steady concentration with frequent occurrence of disorientation; an acceptable task requiring anticipation, but unconventional control technique and pitch motion disconcerting; and a satisfactory task requiring a conventional control technique.

Stenning, T.A., and Dolan, J.A., LATERAL DIRECTIONAL SIMULATION OF THE CL-84 V/STOL AIRCRAFT IN THE TRANSITION REGIME, Paper 64-806, American Institute of Aeronautics and Astronautics and Canadian Aeronautics and Space Institute, Joint Meeting, Ottawa, Canada, October 1964.

Problems in the simulation of the dynamic behavior of a tilt-wing VTOL aircraft in the transition regime are presented. The problems are principally due to the interaction between slipstream, direct-thrust, and normal aerodynamic effects. The objectives of the simulation program are outlined. The basic equations of motion and derivations of the various parameters involved are presented, and the computer-pilot setups are described. The major problem encountered has been the proper representation of turbulence effects, such as inhomogeneous gusts, through the substitution of an aerodynamic force computed as if it applied to a single reference point, i.e., computed as if the aircraft were negligibly small in comparison with the gust wavelength. It is expected that as the program continues and ample funds become available, such problems will be solved by the incorporation of moving-base simulators and external visual displays into the long-range study.

Beilman, J.L., X-22A VARIABLE STABILITY SYSTEM, New York, American Helicopter Society, Inc., 1965, pp II -51 to II -104.

The X-22A variable-stability-and-control VTOL aircraft is described. A functional definition of a variable-stability aircraft is given; its possible uses, advantages, and limitations are enumerated; and the general features of mechanization are described. It is pointed out that the variable stability and control capability, in conjunction with the high control power of the basic aircraft, will make the X-22A unique and a highly useful and versatile tool for research into the flying qualities of the VTOL class of aircraft. The subsystems and devices of the variable stability system are shown.

Anderson, S.B., Quigley, H.C., and Innis, R.C., SOME PERFORMANCE AND HANDLING QUALITIES CONSIDERATIONS FOR OPERATION OF STOL AIRCRAFT, Conference on Aircraft Operating Problems, Ames Research Center, National Advisory Committee for Aeronautics, Moffett Field, California, 1965, pp 309 - 317.

Studies of a number of STOL aircraft show that relatively high maximum lift coefficients and large increases in lift due to power are within the present state of the art. With these lift characteristics, approach speeds of the order of 60 knots for aircraft of moderate wing loading can be realized. Full advantage of the STOL performance of aircraft such as those discussed herein may not be realized on a routine operational basis, however, without some form of damping augmentation system because of lateral-directional handling considerations, particularly for large aircraft operating under instrument flight conditions. Satisfactory characteristics can be obtained by use of only a servo-driven rudder. Additional experience is needed to determine how the STOL aircraft is to be operated before more firm requirements for augmentation systems can be established.

Makarczyk, J.A., and Faith, R., SIMULATION OF HELICOPTER AND V/STOL AIRCRAFT, VOLUME VI, XC-142 ANALOG COMPUTER PROGRAM STUDY: XC-142A SIMULATION EQUATION MECHANIZATION, Melpar Inc., Falls Church, Virginia, January 1965, AD 667 264.

The report presents the analysis and simplification procedures that are required to define the mathematical model for the XC-142A aircraft in a form which is suitable for mechanization and solution on a general-purpose analog computer. This program will enable the Naval Training Device Center to perform dynamic simulation studies for a V/STOL tilt-wing aircraft. Section II contains the complete mathematical model of the XC-142 with accompanying denotation and validation. In Section III, three sets of simulation equations are presented. These sets represent the complete six-degree-of-freedom equations, longitudinal mode equations, and lateral-directional mode equations. Section IV contains the mechanization functional block diagrams along with the patching and operating instructions required for their utilization. Section IV also specifies the analog computer installation which is required to solve the mechanizations. The subsequent sections contain a discussion of program limitations, conclusions, and recommendations.

Kaufman, L.A., A CONCEPT FOR THE DEVELOPMENT OF A UNIVERSAL AUTOMATIC FLIGHT CONTROL SYSTEM FOR VTOL AIRCRAFT, American Helicopter Society, Journal, Vol. 10, January 1965, pp 19-34.

The possibility of achieving a universal automatic flight control system for VTOL aircraft is explored. The objectives of basic automatic flight control functions in present applications are reviewed. The paper then proceeds to the description of a potentially realizable universal automatic flight control system. This system is built around a core system which replaces the typically mechanical flight control system with "fly-by-wire" controls. Some of the leading problems associated with the actual development of such a system are indicated.

Kuhn, R. E., and Hammond, A. D., CONTROL REQUIREMENTS AFFECTING STOLS, Astronautics and Aeronautics, Vol. 3, May 1965, pp 48-52.

Requirements for the adequate control of short takeoff/landing (STOL) aircraft are discussed. Available high-lift systems for achieving the low speeds needed to operate into and out of small fields are reviewed, and limitations on the applicability of these systems are discussed. The handling quality requirements and lateral and longitudinal control requirements for STOL aircraft are examined, and the low-speed operational envelope for the landing and takeoff of the STOL is described.

Curry, P. R., and Matthews, J. T., SUGGESTED REQUIREMENTS FOR V/STOL FLYING QUALITIES, USAAML TR 65-45, RTM-37, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, June 1965, AD 617 748.

Suggestions for a specification on flying and handling qualities requirements for subsonic V/STOL aircraft are presented. In addition to including the ideas of many others, the authors have incorporated two basic suggestions: (1) the use of a pilot rating system (since the ultimate measures of handling qualities are determined by the pilot) and (2) the use of servo-analysis techniques and terms to define quantitative requirements. There are no statistical or quantitative data available to verify the stated requirements in some cases; however, the requirements are based on many different V/STOL research aircraft funded by the U.S. Army and flown by U.S. Army pilots.

Anderson, S. B., Quigley, H. C., and Innis, R. C., STABILITY AND CONTROL CONSIDERATIONS FOR STOL AIRCRAFT, AGARD Report 504, Advisory Group for Aeronautical Research and Development, Paris, France, June 1965.

McGregor, D. M., SIMULATION OF THE CANADAIIR CL-84 TILT-WING AIRCRAFT USING AN AIRBORNE V/STOL SIMULATOR, NAE LR-435, National Aeronautical Establishment, National Research Council, Ottawa, Canada, July 1965.

A simulation of the Canadair CL-84 tilt-wing aircraft using an airborne V/STOL simulator is described. This program was undertaken to assess the influence on the handling qualities of (1) backlash and flexibility in various locations in the control systems and (2) various realistic stability augmentation failures in the presence of these backlashes. The tests were completed before the actual aircraft flew; Canadair was provided with positive indications of what backlashes could be tolerated and the company pilots were thoroughly familiarized with the flying and control system characteristics to be expected.

Klingloff, R. F., Sardanowsky, W., and Baker, R. C., THE EFFECT OF VTOL DESIGN CONFIGURATION ON POWER REQUIRED FOR HOVER AND LOW SPEED FLIGHT, American Helicopter Society, Journal, Vol. 10, July 1965, pp 2-14.

Results for five armed tactical aircraft for those low-speed maneuvers that are most power-dependent, i. e. , acceleration and sustained load factor, are analyzed. Sustained maneuvers prohibit the use of stored energy by any of the propulsion systems. The aircraft considered, which were capable of performing a specified mission, included a compound helicopter, a tilt-wing and propeller V/STOL aircraft, a tilt-propeller VTOL aircraft, a lift-fan VTOL aircraft, and a tandem tilt-propeller VTOL aircraft. The factors affecting the ability of VTOL aircraft to accelerate and generate sustained load factors and therefore steady-state turn rates are power available, control power requirements, rotor stall, positive and negative wing stall, propeller stall, and fan stall. The power required to comply with specifications for control of pitch, roll, and yaw is shown for each of the VTOL aircraft as a percentage of hover power required. The superiority of the rotor and tail-rotor combination of the compound helicopter for producing control moments efficiently is considered to be clearly indicated. The maximum static thrust-to-weight ratio available when installed power is established by hover and compliance with control power specifications is discussed.

Lollar, T. E., Bus, F. J., and Dolliver, D. M., CONTROL REQUIREMENTS AND CONTROL METHODS FOR LARGE V/STOL AIRCRAFT, Paper 650808, Society of Automotive Engineers, National Aeronautics and Space Engineering and Manufacturing Meeting, Los Angeles, California, October 1965.

Control problems of large V/STOL transport aircraft, with analysis of control power requirements and their influence on hardware design and aircraft weight, are discussed. The control power requirements include stabilization and control of external disturbances and basic maneuvering. It is shown that the stabilization required decreases with increasing design weight. The maneuvering control required is essentially independent of weight and may be installed as an angular control or a linear translation control. Of the various configurations evaluated,

it is considered that reaction control systems that contribute to lift at the same time that control is being provided produced the highest aircraft weights. The control air source giving the lightest aircraft weight was the use of separate control engines at the aircraft extremities. However, installation problems for this type of control make bleed-burn or bleed systems using centrally located turbocompressors look more attractive.

Holzhauser, C.A., Innis, R.C., and Vomaske, R.T., A FLIGHT AND SIMULATOR STUDY OF THE HANDLING QUALITIES OF A DEFLECTED SLEPSTREAM STOL SEAPLANE HAVING FOUR PROPELLERS AND BOUNDARY-LAYER CONTROL, NASA TN D-2966, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California, September 1965.

Flight and simulator tests were made to study low-speed handling qualities, potential STOL problem areas, and causes of deficiencies and their solutions. Tests of the STOL seaplane were made in the 50- to 60-knot speed range with automatic stabilization equipment (ASE) engaged and disengaged. During the simulation, several stability and damping derivatives were varied and evaluated. During the flight tests, takeoffs and landings were made from water at 50 knots, corresponding to a lift coefficient of about 4. With the ASE engaged, the handling characteristics of the aircraft were unsatisfactory because of low static longitudinal stability, a very unstable spiral mode, and large sideslip excursions during turn entries. Response to control inputs was satisfactory about the roll and pitch axes, but the like rotation propellers reduced the directional control to an unsatisfactory level. The simulator tests were useful in providing a preliminary evaluation and in studying the causes of deficiencies and their solutions. Good correlation was obtained between the simulator and flight results with the exception that the sideslip excursions during maneuvering were larger in flight than on the simulator.

Nettleton, T.R., HANDLING QUALITIES RESEARCH IN THE DEVELOPMENT OF A STOL UTILITY TRANSPORT AIRCRAFT, Paper 65-713, Canadian Aeronautics and Space Institute and American Institute of Aeronautics and Astronautics, Low-Speed Flight Meeting, Montreal, Canada, October 1965.

The stability and control research conducted by de Havilland Aircraft of Canada during the design of the twin-engine, propeller-driven DHC-5 Buffalo STOL utility transport is discussed, and flight test results are reviewed. The Buffalo evolved from a series of design studies of the weight and power growth potential of the DHC-4 Caribou. A slot-lip aileron control system was studied which contributed significantly to good lateral behavior in stalls. It was found that a considerable increase in rudder effectiveness could be achieved if a power control system was used. Problems of directional stability were encountered and solved. Extensive

research was carried out in the areas of longitudinal stability and control. Selective integration of analytical studies, and wind-tunnel and flight research led to a relatively unsophisticated design which complied with all stability and control objectives.

McGregor, D. M., and Smith, R. E., HANDLING QUALITIES RESEARCH AT THE NATIONAL AERONAUTICAL ESTABLISHMENT, OTTAWA, USING AIRBORNE V/STOL SIMULATIONS, Paper 65-705, Canadian Aeronautics and Space Institute and American Institute of Aeronautics and Astronautics, Low-Speed Flight Meeting, Montreal, Canada, October 1965.

A brief description of the two V/STOL aircraft simulators operated by the National Aeronautical Establishment is presented. One of these variable-stability helicopter simulators has the capability of varying its characteristics in the three rotational degrees of freedom over wide limits and has been "flying" for several years. The other uses the same basic "model-controlled" method of simulation but has many improvements, including the capacity to alter its response in the vertical or heavy degree of freedom. These aircraft simulators have been used for general research into V/STOL handling qualities requirements and for simulation of particular aircraft. An example of the former, which is outlined, is an investigation into the effects of various levels of weathercock stability on directional handling qualities during both a visual and simulated instrument piloting task. A simulation of the Canadair CL-84 tilt-wing V/STOL aircraft, with particular emphasis on control systems characteristics, was conducted and the results are presented. This investigation, among other things, established limits of backlash in various control systems for satisfactory flying qualities with the CL-84 stability augmentation system engaged and for acceptable behavior following a variety of stability augmentation failures.

Anderson, S. B., Quigley, H. C., and Innis, R. C., STABILITY AND CONTROL CONSIDERATIONS FOR STOL AIRCRAFT, AGARD Report 504, Advisory Group for Aeronautical Research and Development, Paris, France, June 1965.

Experience obtained with STOL aircraft weighing from 3000 to 150,000 lb is reviewed, with reference to lift performance, limitations in low-speed operation, solutions of handling qualities problems, and test methods used to investigate stability and control characteristics. The discussion is confined to the low-speed landing approach portion of the flight regime. Special features of the aircraft studied included flaps combined with drooped ailerons, highly deflected flaps with boundary layer control (BLC), immersion of the wing in the slipstream, large deflection-angle control surfaces with BLC, high thrust-to-weight ratio, counter-rotating and interconnected propellers, stability augmentation devices, cockpit

controls, and the use of propeller pitch to augment lateral and directional control. Large increases in lift were achieved, but it is difficult to realize the full advantages without stability augmentation.

Curtiss, H. C., AN ANALYTICAL STUDY OF THE DYNAMICS OF AIRCRAFT IN UNSTEADY FLIGHT, Princeton University, USAAVLABS Technical Report 65-48, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, October 1965, AD 627 370.

The dynamic response of conventional and VTOL aircraft with varying flight velocity is investigated. It is assumed that the dynamic motions of aircraft may be described by linear differential equations whose coefficients (stability derivatives) are functions of flight velocity, and therefore vary with time. Primary emphasis is placed on the evaluation of the general nature of the vehicle response and its departure from frozen system (constant coefficients) characteristics.

Stapleford, R. L., Wolkovitch, J., Magdeleno, R. E., Shortwell, C. P., and Johnson, W. A., AN ANALYTICAL STUDY OF V/STOL HANDLING QUALITIES IN HOVER AND TRANSITION, TR-140-1, Systems Technology Inc., Hawthorne, California, 1965.

The hover analysis considers pilot attitude and position control tasks in the presence of horizontal gusts. The effects of each of the stability derivatives on the difficulty of the control tasks and on the closed-loop gust response are determined. It is shown that the handling qualities studies of control sensitivity and angular damping must consider the influences of  $M_{\text{sub } U}$  (or  $L_{\text{sub } V}$ ) and should include gust inputs. These conclusions are substantiated by previous variable-stability helicopter experiments. The effects of vehicle size and geometry are investigated by several approaches. The key result of increasing the size is found to be a reduction in  $M_{\text{sub } U}$  and  $L_{\text{sub } V}$ , which can, in turn, lower the requirements for control power and damping. The handling qualities during transition of two vehicles, a tilt duct and a tilt wing, which were previously tested on a simulator are analyzed. It is shown that both trim control and perturbations about the trim conditions must be considered. In fact, part of the increased difficulty in landing transitions, in comparison with takeoff transitions, is due to more difficult trim control; the much more stringent position control requirements in landing are also a contributing factor.

Steils, W. T., Jr., V/STOL HOVER CONTROL SYSTEM ANALYSIS, Paper 65-799, Aircraft Design and Technology Meeting, Los Angeles, California, American Institute of Aeronautics and Astronautics, Royal Aeronautical Society, and Japan Society for Aeronautical and Space Sciences, 1965.



The results of a study of the propulsion system/control system interface for several V/STOL hover control concepts in aircraft using the lift plus lift-cruise propulsion concept are presented. The control concepts included are proportional reaction controls using lift engine compressor bleed air, engine thrust modulation, and engine thrust vectoring. The effects on control system performance of reaction control thrust augmentation by duct burning are shown. These control concepts are applied to three subsonic V/STOL strike-reconnaissance fighter aircraft of different gross weights, and the concepts are compared on the basis of bleed air requirements, thrust-to-weight ratio penalties, and lift engine operating limitations. It is shown that the use of duct burning augmentation and engine thrust vectoring control concepts produce significant performance improvements and simplify lift engine design requirements.

Anon., EFFECTS OF AIRCRAFT SIZE ON CRITERIA FOR HOVERING AND LOW SPEED CONTROL CHARACTERISTICS, Defense Documentation Center Summary Acc. No. NR000513, Langley Research Center, Langley Station, Virginia, April 1966.

The purpose of this work was to establish the effects of size on the performance of helicopters and other V/STOL aircraft in or near the hovering regime of flight. This work was to clarify some of the results obtained from both fixed- and moving-base simulation studies at various places throughout the country and from flight tests of various sizes and configurations of aircraft.

Anderson, S. B., HANDLING QUALITIES REQUIREMENTS AND OPERATIONAL LIMITATION FACTORS IN LANDING APPROACH FOR LARGE STOL AIRCRAFT, Ames Research Center, Moffett Field, California, Defense Documentation Center Summary Acc. No. NR000407, April 1967.

The handling qualities requirements for large STOL aircraft, and their applications to large propeller-driven STOL transport-type aircraft are studied. Flight tests are required to correlate pilot opinion with quantitative measurements of control power about all axes, static and dynamic stability, maneuvering characteristics, trim changes, landing and takeoff characteristics, asymmetric power conditions, and stall characteristics.

Curtiss, H. C., Putman, W. F., and Lebacqz, J. V., AN EXPERIMENTAL INVESTIGATION OF THE LONGITUDINAL DYNAMIC STABILITY CHARACTERISTICS OF A FOUR-PROPELLER TILT-WING VTOL MODEL, Princeton University, USAAVLABS Technical Report 66-80, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, September 1967, AD 663 848.

The results of experiments conducted to evaluate the longitudinal stability characteristics of a 1/10-scale dynamic model of a four-propeller tilt-wing VTOL transport are presented and discussed. The Princeton Dynamic Model Track was used to measure the static stability and the transient response of the model at wing incidences from 90° to 40°. The results are interpreted in terms of full-scale aircraft characteristics. All data are presented for a C.G. position of 90% MAC (the most forward C.G. position of the aircraft is 15% MAC), and the horizontal tail and flap program differ from those presently used on the aircraft. The transient motions at wing incidences above 70° were similar and dominated by high-speed stability and low angular damping, resulting in an unstable oscillation of approximately a 9-second period for the full-scale aircraft. The responses at wing incidences below 70° were more complex due to a rapid decrease in the speed stability from a large positive value above 70° to a negative value at 60°. The values of the speed stability for the aircraft determined by a detailed analysis of the data in the neighborhood of 60° wing incidence differ from those obtained from a preliminary analysis of the data by the LTV Aerospace Corporation. Typically, at wing incidences between 60° and 40°, the linearized static stability derivatives  $M_u$  and  $M_a$  were small, nonlinearities were evident, and the small-amplitude linearized motion was dominated by a divergence. At 40° wing incidence, indications were that the dynamic motions were becoming stable.

MacCabe, R. S., VERTICAL FLIGHT PERFORMANCE CRITERIA, Army Combat Developments Command Aviation Agency, Fort Rucker, Alabama, June 1968, AD 840 304.

Various problems confronting military operators of VTOL aircraft in tactical environments which tend to impede the ability to hover and perform related vertical flight maneuvers are examined. Several modes of flight used in certain tactical situations were examined to establish appropriate power and lift requirements in excess of ambient temperature, high elevation, wind, and aircraft and engine deterioration. Periodic aircraft weight increases and operator skill levels are evaluated. These factors are appropriately interrelated, and allowances are suggested to provide continued satisfactory vertical flight performance in service. Recommended vertical performance criteria for application in concept formulation studies, materiel requirements, and specifications for future Army tactical VTOL aircraft are provided.

Black, E. L., CORRELATION OF STABILITY AND CONTROL DERIVATIVES OBTAINED FROM FLIGHT TESTS AND WIND TUNNEL TESTS ON THE XC-142, Ling-Temco-Vought, Inc., Air Force Dynamics Laboratory, Wright-Patterson AFB, Ohio, Defense Documentation Center Summary Acc. No. DF 475524, 15 July 1968.

An investigation was performed to correlate the aerodynamic stability and control characteristics derived from flight test data of the XC-142 with the same derivatives as determined by the wind-tunnel studies which have been conducted in various low-speed tunnels and test facilities; particular emphasis is on transition and hover.

Skelton, G. B. , INVESTIGATION OF THE EFFECTS OF GUSTS ON V/STOL AIRCRAFT IN TRANSITION AND HOVER, AFFDL-TR-68-85, Honeywell, Inc. , Air Force Flight Dynamics Laboratory, Dayton, Ohio, October 1968, AD 679 593.

This investigation concerns the development of statistical models for the gust environment in the earth's boundary layer for use in determining the gust response characteristics of V/STOL aircraft. A general gust model based upon published gust data was developed, and analyses of V/STOL response with that model were conducted to determine the gust descriptors significant to V/STOL performance. An interim gust model embodying the significant descriptors was then developed for use in V/STOL gust analyses. Meteorological experiments to measure the significant gust descriptors determined from the analyses are the diagonal terms of the gust covariance tensor, gust probability distributions, mean wind probability distributions, and the dependencies of these statistics on thermal stability, surface roughness, and altitude. Less critical descriptors include the off-diagonal components in the gust covariance tensor and the space-time interplay in that tensor. The significant gusts seen by the aircraft are head-on and vertical gusts on the wings; head-on and vertical gust shears across the wings; head-on, side, and vertical gusts on the tail; and head-on and side gusts on the fuselage. Mean airspeed and sideslip angle are important parameters in V/STOL gust responses. The wing-to-tail transport delay of the gusts in forward flight also has a significant effect. V/STOL gust responses at low airspeeds are generally small due to the low dynamic pressures, and the responses are decidedly nonlinear except at low gust amplitudes.

Crane, H. L. , Sommer, R. W. , and Healy, F. M. , EFFECTS OF REDUCED AIRSPEED FOR LANDING APPROACH ON FLYING QUALITIES OF A LARGE JET TRANSPORT EQUIPPED WITH POWERED LIFT, NASA TN D-4804, Langley Research Center, National Aeronautics and Space Administration, Langley Station, Virginia, October 1968.

A flight research program was conducted to determine the effects of reduced landing approach speeds on the flying qualities of a typical large jet transport for simulated instrument approaches. The reduced approach speeds were made possible by a powered lift system which blew air over the upper surface of the wing flaps. The effects of reduced approach speeds on flying qualities and flying qualities requirements are discussed. It was found that a 25% reduction in landing approach speed would not necessarily result in new requirements for

satisfactory flying qualities. However, such items as pitch response and trim characteristics, Dutch roll damping, and lateral directional coupling are likely to be more difficult to maintain at satisfactory levels.

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**This document lists approximately 280 papers, articles, and reports that deal with VTOL flying qualities. This bibliography is organized as follows: flying qualities specifications and recommended requirements; conferences and bibliographies; papers and articles; NATO-AGARD reports; National Research Council of Canada Reports; Great Britain Reports; Company, University, Research Laboratory Reports; and U.S. Government Agencies.**

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A bibliography on VTOL/STOL aircraft is presented for literature published from 1963 to 1965. The bibliography contains approximately 820 references in the following subject categories: types of V/STOL aircraft, aerodynamic problems, handling characteristics, propulsion systems, test techniques, operational problems, and loads and structures. In addition, a detailed subject index, a personal author index, and a source/corporate source index are provided, all of which include a notation of content for each entry. The source/corporate source index includes not only corporate sources, but also journal and periodical sources and patents. The choice of subject headings is based largely on those used in Scientific and Technical Aerospace Reports and International Aerospace Abstracts.

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author): Convair Division of General Dynamics San Diego, California		22. REPORT SECURITY CLASSIFICATION Unclassified
		23. GROUP
3. REPORT TITLE EFFECT OF HIGH-LIFT DEVICES ON V/STOL AIRCRAFT PERFORMANCE VOLUME II - BIBLIOGRAPHY		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report		
5. AUTHOR(S) (First name, middle initial, last name) Joseph Hebert, Jr. S. K. Pederson		
6. REPORT DATE July 1970	7A. TOTAL NO. OF PAGES 224	7B. NO. OF REFS
8A. CONTRACT OR GRANT NO. DAAJ02-69-C-0079	8B. ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 70-33B	
8C. PROJECT NO. Task 1F162204A14231		
8D. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)		
10. DISTRIBUTION STATEMENT This document is subject to special export controls, and each transmittal to foreign governments or foreign nationals may be made only with prior approval of U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604.		
11. SUPPLEMENTARY NOTES Volume II of a 2-volume report	12. SPONSORING MILITARY ACTIVITY U. S. Army Aviation Materiel Laboratories Fort Eustis, Virginia	
13. ABSTRACT This bibliography is a part of the contracted effort "Effects of High-Lift Devices on V/STOL Aircraft Performance", Contract DAAJ02-69-C-0079. All types of high-lift devices are covered. Both experimental and theoretical topics were reviewed, and the selected reports are listed by a subject and an author index.		

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OBSOLETE FOR ARMY USE.

Unclassified

Security Classification

14	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
	Airplanes, V/STOL Airplanes, Tilt-Wing Airplanes, Deflected Slipstream Airplanes, Tilt Prop High-Lift Devices Jet Flaps Boundary Layer Control Downwash Ground Effects Tunnel Wall Effects Handling Characteristics						